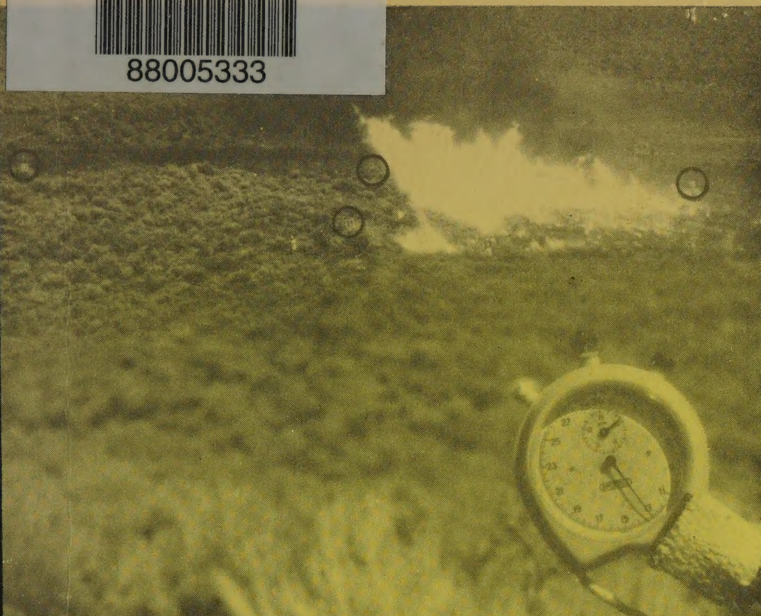

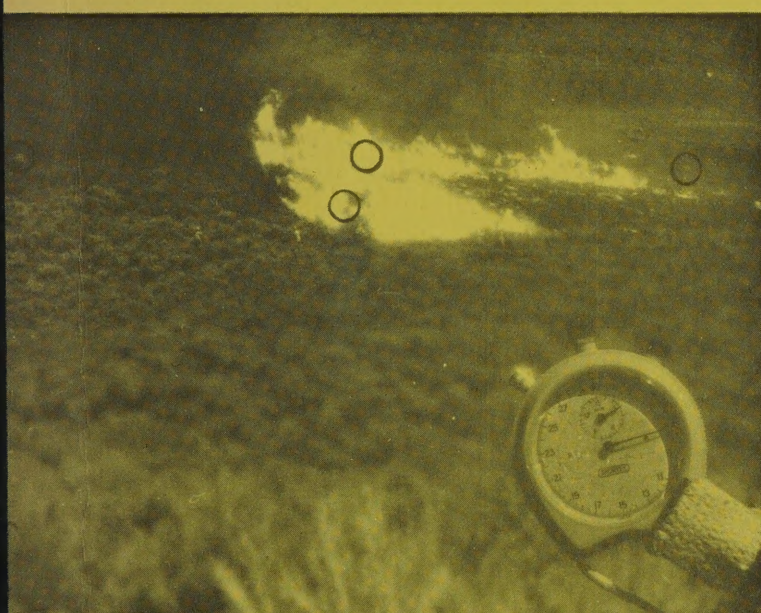

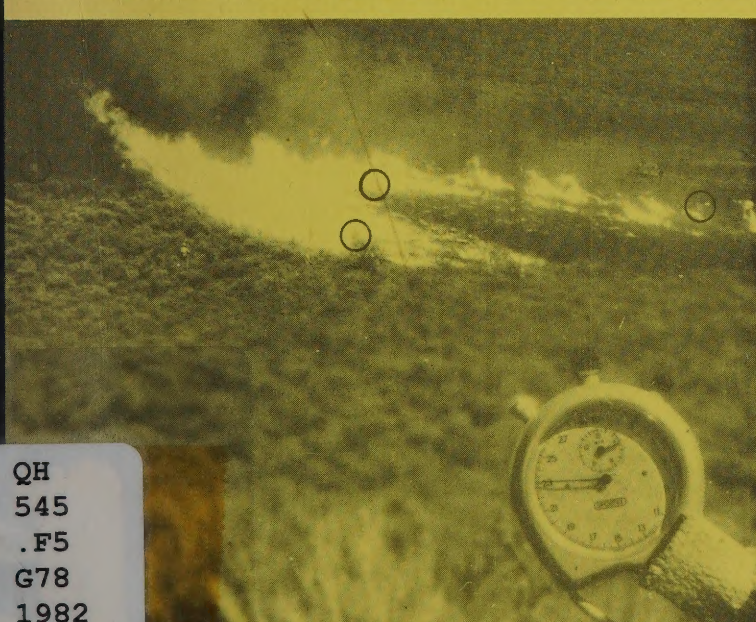

GREAT BASIN RATE-OF-SPREAD STUDY

FIRE BEHAVIOR/FIRE EFFECTS

November 1982

BUREAU OF LAND MANAGEMENT
NEVADA STATE OFFICE
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ABSTRACT

Results of observational studies on prescribed burns completed in July and October of 1980, near Ely and Elko, Nevada, and fire behavior data from August 1981, burns near Carson City, Nevada, are reported. Responses to fire of plant individuals from the 1980 burns are compared to expectations based on reviews of the fire effects literature for each species examined. Similarities and differences between expected and actual plant responses are discussed with reference to the fire behavior and other factors related to the burns. A conceptual model of the information flow in predicting fire effects is presented. Fire behavior and plant responses data are presented in graphic form. The report concludes with a list of recommendations for future study.

Cover: Three infrared, time sequence photos of the test burn near Ely, Nevada. Reference placards (6 foot post with a 2 foot by 2 foot asbestos marker on top) are circled. Stopwatch was photographed using a split-field filter.

THE AUTHORS

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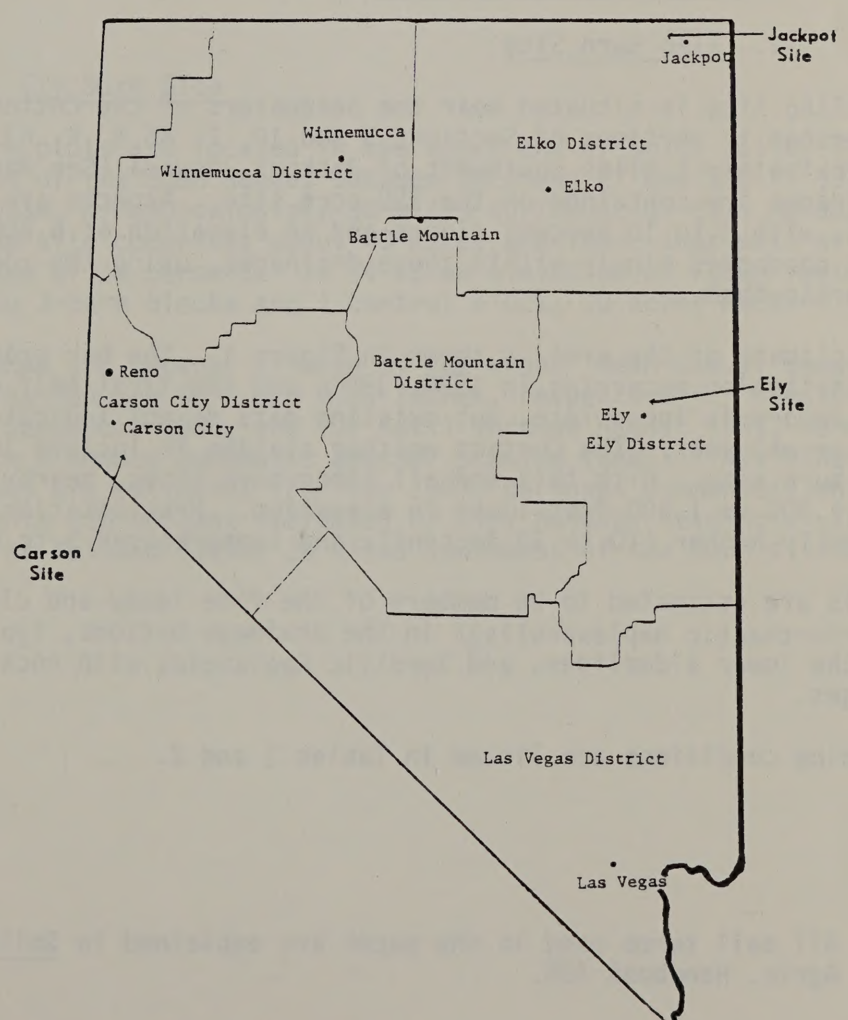
I. INTRODUCTION

In the summer of 1980, the Nevada State Office of the Bureau of Land Management (BLM) initiated the Great Basin Rate-of-Spread Study with the objective of calibrating predictive models of fire behavior for use in sagebrush type fuels. Reports 1 and 2 discuss this earlier work. (Range and others 1980). The fire behavior prediction techniques studied were developed by the U.S. Forest Service Northern Forest Fire Laboratory (NFFL) to enable managers to assess potential fire rate-of-spread and fire intensity, given conditions of fuel type, weather, and topography. Such fire behavior information is necessary for efficient dispatch of suppression forces in wildfire situations and for planning cost-effective prescribed burns. However, fire managers in Nevada and other Great Basin states felt that predictions were not matching field observations well enough for operational use of the models. The Nevada State Office conferred with the NFFL and designed a study to calibrate the fire prediction outputs for sagebrush and sagebrush/grass fuels, especially those related to fuel models used in the TI-59 Fire Danger/Fire Behavior hand-held calculator programs. Three study locations were selected (See Map 1).

Map 1. Nevada Bureau of Land Management Disticts and Study Site Locations.



During the course of the fire behavior studies, the authors recognized the opportunity to observe the effects of study burns on the plants involved. This situation was particularly attractive because the actual burn data were available to account for the plant responses, such as mortality, resprouting, and species composition changes. We were able to describe, in quantitative terms, how the fire related to the effects. This is similar in principle to range trend analysis, with which Bureau personnel are familiar. A quantified fire event, like stocking or grazing pressure data, is included in the analysis of range condition and trend.

Past studies of fire effects most often have focused on after-the-fact situations, where fire behavior information was unavailable or not discussed. In the rare instances where fire behavior is addressed, the use of subjective terms such as "hot", "cool", "running", or "spotting" hinders meaningful correlation of the fire to its effects. These general terms make it nearly impossible to compare the results of different studies (Rothermel and Deeming 1980). This fire effects study attempts to bring current information from fire effects literature together with analysis of actual fire behavior observations. Fire management of Bureau lands can thus benefit by having decisions based on direct experience with the ecology of the resources the Bureau is to protect.

A. Description of Study Sites

1. Elko Burn Site

The Elko site is situated near the headwaters of the Cottonwood Creek watershed in portions of Sections 3 and 10, T. 46 N, R. 63 E, MDB&M or approximately 8 miles southwest of Jackpot, Nevada (See Map 1). Four small drainages are contained on the 150 acre site. Aspects are north to north-east, with 2 to 10 percent slopes and an elevation of 6,600 feet. The burns were conducted singly within these drainages, using the rocky ridges to separate them.

The climate of the area is shown in Figure 1. The bar graph represents precipitation occurring in 1980, 1981, and the first half of 1982. The record is incomplete, but existing data do not indicate an abnormally dry or wet year. The Contact weather station is located 10 miles south of the burn site. With this and all other burn sites, nearby weather stations are 1,000 to 1,800 feet lower in elevation. Precipitation values would be slightly higher (10 to 30 percent), and temperatures 5 to 6 degrees lower.

Soils are estimated to be members of the fine loamy and clayey families of Torriorthentic Haplexerolls1/ in the drainage bottoms, Typic Argixerolls on the lower sideslipes, and Xerollic Haplargids with rock outcrops on the ridges.

Burning conditions are listed in Tables 1 and 2.

1/ All soil terms used in the paper are explained in Soil Taxonomy. USDA Agric. Handbook 436.

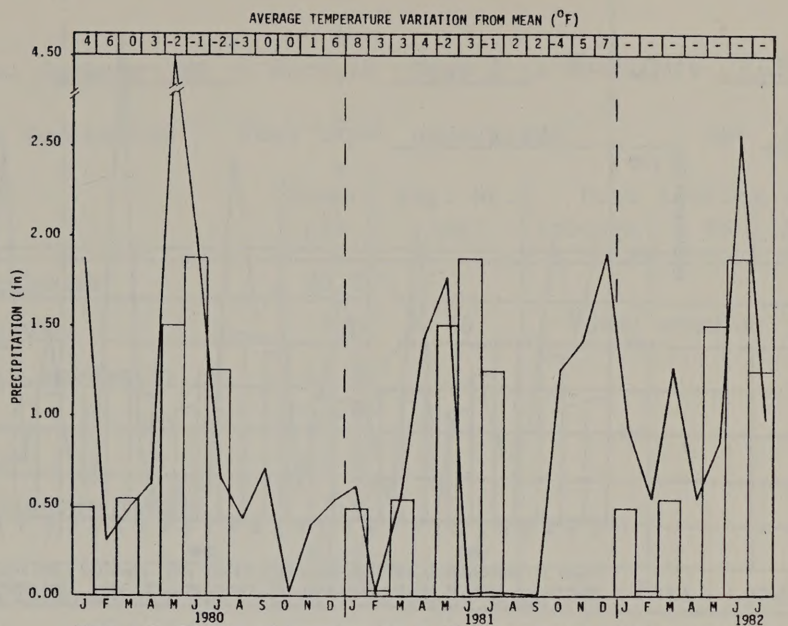


Figure 1. Precipitation and temperature data for Elko site, elevation 6,600 feet. (Contact, NV, elev. 5,365). Mean monthly precipitation ⌐¬, 1980-1982 precipitation——. Average monthly temperature variation from the mean +/-.

2. Ely Burn Site

The Ely burn plots are located in the upper end of Smith Valley (Horse Haven), west of the Egan Range, between Sections 27 and 28, T. 19 N, R. 62 E, MDB&M, or approximately 16 miles northwest of Ely, Nevada (See Map 1). The site comprises about 40 acres and faces southeast with an average slope of 12 percent. It is at an elevation of 7,500 feet. It is divided into 3 burn blocks and 1 control block, 10 acres each.

Figure 2 shows the general climate of the area. Mean annual temperature and precipitation are 44°F and 8.84 inches, respectively. Precipitation values for September 1980, and for April through August 1981, were obtained on site with a Remote Automatic Weather Station (RAWS). All other precipitation values are estimates (Porfido 1981; personal communication) based on adjustments (30 percent increase) of Ely, Nevada, readings. The station is located at Yelland Field, 16 miles southwest of the burn site.

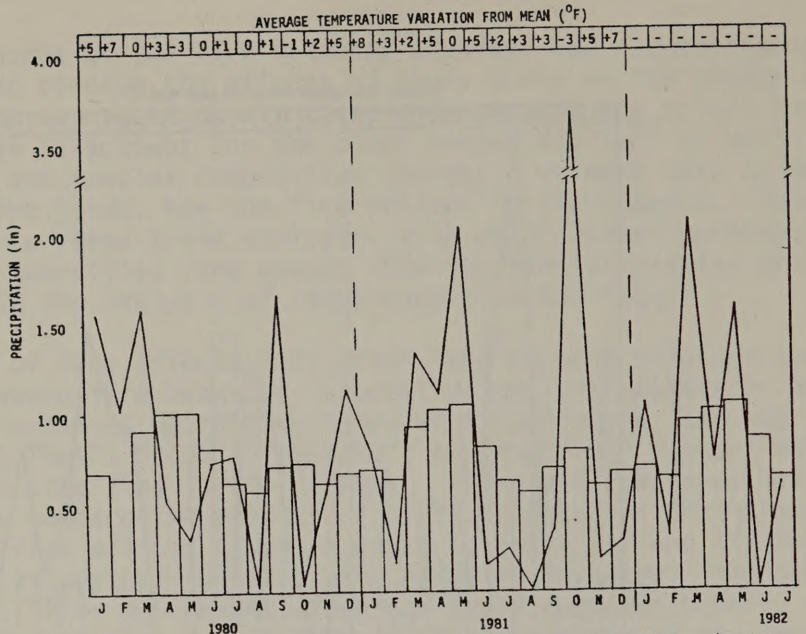


Figure 2. Precipitation and temperature data for Ely site, elevation 7,500 feet. (Weather observations taken at Yelland Field, Ely, NV, elevation 6,200 feet.) Mean monthly precipitation ⊓, 1980-1982 precipitation ——, and average monthly temperature variation from the mean +/-.

Abundant precipitation followed the August and October 1980 burns. This trend continued through the winters of 1980 and 1981 and in spring of 1981 and 1982. The typical summer drought was more severe than normal in 1981.

Soils are derived from quartzite and volcanic rocks and are classified into the Simme series (Kiracofe 1981; personal communication), which is a member of the loamy-skeletal mixed frigid family of Aridic Argixerolls, with associated Mascump series (loamy-skeletal mixed frigid Aridic Lithic Argixerolls) and rock outcrop. Depth to bedrock is about 26 inches. Soil analysis data are presented in Appendix A.

Burning conditions for Ely burns 1 and 2 are listed in Tables 3 and 4.

3. Carson Burn Site

The Carson site lies within the Pine Nut Mountains (Lebo Springs), in Section 30, T. 14 N, R. 22 E, MDB&M, Dayton, Nevada, NV quadrangle at 6,600 feet elevation (See Map 1). The study area measures 1,300 feet long, running northeast-southwest, by 600 feet wide. It is a flat area, with an average slope of three percent facing southwest. Moderate slopes, covered with pinyon-juniper, surround the flat on three sides with the open end facing the prevailing southwest wind. The 20 acre site is divided into eight equal blocks.

Mean monthly precipitation and temperature are given in Figure 3. Mean annual values are 8.51 inches for precipitation and 48.8°F for temperature. Postburn rainfall will be presented in a future update of Lebo site fire effects.

Table 1. Summary of Burning Conditions for Elko Burn 1.

I. Site

A. Location Jackpot, NV ; Burn ID Draw 1 ; Burn Date 8/27/80 .

B. Preburn Vegetation Fuel Type sage/grass Age 45 years

Species	Cover (%)	Avg. Ht. (cm)	Fuel Loading (T/A) Foliage	1 HR	10 HR	100 HR
big sagebrush	25.0	76	Total shrubs: 1.76			
rabbitbrush	5.0					
mountain snowberry	12.0					
lupine	2.0					
grasses*	2.0					
miscellaneous forbs	3.0					
litter	43.0					
bare ground	4.0		Total Loading : 3.48			

61 cm Fuelbed Depth (80% average)

C. Topography: Elevation 6,600 Ft; Slope 6 %; Aspect N ; Position on slope in bottom of small drainage .

II. Environment

A. Time 1100 Season late summer

B. Weather: Air Temperature 74 °F; Relative Humidity 24 %

Wind Speed Minimum - mph, Maximum - mph, Average 5 mph

Wind Direction S ; Slope Degrees 0 (0-360°); instrument Ht. 6 Ft.

C. Moisture Contents Live and Dead (percent oven-dry weight)

Species	Live: Foliage	0-¼"	¼-1"	1"+	Dead: 1HR	10 HR	100 HR
sagebrush	98				4	5	5
rabbitbrush	101						
mountain snowberry	79						
bluegrass	33						

Soil Moisture: 6 % at 15 cm depth.

*Idaho fescue, bottlebrush squirreltail, cheatgrass, bluegrass, Great Basin wildrye.

Table 2. Summary of Burning Conditions for Elko Burn 2.

I. Site

A. Location Jackpot, NV ; Burn ID Draw 4 ; Burn Date 10/6/80 .

B. Preburn Vegetation   Fuel Type sage/grass   Age 45 years

Species	Cover (%)	Avg. Ht. (cm)	Fuel Loading (T/A) Foliage	1 HR	10 HR	100 HR
big sagebrush	6.5					
mountain snowberry	19.0	65	data not available			
green rabbitbrush	3.0					
standing dead shrubs	21.5					
litter	50.0					
bare ground	0.0					
			Total Loading : -			

52 cm Fuelbed Depth (80% average)

C. Topography: Elevation 6,600 Ft; Slope 12 %; Aspect N ; Position on slope bottom of small drainage .

II. Environment

A. Time 1130   Season fall

B. Weather: Air Temperature 70 °F; Relative Humidity 27 %

Wind Speed Minimum - mph, Maximum - mph, Average 5 mph

Wind Direction E-S ; Slope Degrees 90-270 (0-360°); instrument Ht. 6 Ft.

C. Moisture Contents Live and Dead (percent oven-dry weight)

Species	Live: Foliage	0-¼"	¼-1"	1"+	Dead: 1HR	10 HR	100 HR
big sagebrush	49	41			9	5	4
mountain snowberry	35						
green rabbitbrush	34						

Soil Moisture: 10 % at 15 cm depth.

Table 3. Summary of Burning Conditions for Ely Burn 1.

I. Site

A. Location Ely, NV ; Burn ID Block 1 ; Burn Date 8/29/80 .

B. Preburn Vegetation Fuel Type sage/grass Age 35 years

Species	Cover (%)	Avg. Ht. (cm)	Fuel Loading (T/A) Foliage	1 HR	10 HR	100 HR
big sagebrush	19.0	87				
antelope bitterbrush	18.0	89	1.16	0.74	0.78	
green rabbitbrush	9.0	29				
Utah snowberry	trace					
grasses	20.0					
forbs	0.0					
litter	5.0		0.35			
bare ground	29.0		Total Loading : 3.03			

70 cm Fuelbed Depth (80% average)

C. Topography: Elevation 7,500 Ft; Slope 12 %; Aspect SE ; Position on slope midslope .

II. Environment

A. Time 1400 Season late summer

B. Weather: Air Temperature 89 ^{o}F; Relative Humidity 14 %

Wind Speed Minimum 6 mph, Maximum 10 mph, Average 8 mph

Wind Direction W-SW ; Slope Degrees 0 (0-360^{o}); instrument Ht. 6 Ft.

C. Moisture Contents Live and Dead (percent oven-dry weight)

Species	Live: Foliage	0-¼"	¼-1"	1"+	Dead: 1HR	10 HR	100 HR
big sagebrush	100				4	3	
antelope bitterbrush	96						
green rabbitbrush	86						
Utah serviceberry	95						
Utah snowberry	81						
herbaceous	29						

Soil Moisture: 7 % at 15 cm depth.

Table 4. Summary of Burning Conditions for Ely Burn 2.

I. Site

A. Location Ely, NV ; Burn ID Block 2 ; Burn Date 10/6/80 .

B. Preburn Vegetation Fuel Type sage/grass Age 35 years

Species	Cover (%)	Avg. Ht. (cm)	Fuel Loading (T/A) Foliage	1 HR	10 HR	100 HR
big sagebrush	10.0	64				
low sagebrush	5.0					
antelope bitterbrush	9.0	108	date not available			
green rabbitbrush	10.0	35				
Utah snowberry	2.0	111				
standing dead shrubs	6.0		Total dead 3.5			
litter	38.0					
bare ground	20.0		Total Loading : -			

88 cm Fuelbed Depth (80% average)

C. Topography: Elevation 7,500 Ft; Slope 2 %; Aspect SE ; Position on slope midslope .

II. Environment

A. Time 1300 Season fall

B. Weather: Air Temperature 74 °F; Relative Humidity 16 %

Wind Speed Minimum 2 mph, Maximum 10 mph, Average 3 mph

Wind Direction S ; Slope Degrees 45 (0-360°); instrument Ht. 6 Ft.

C. Moisture Contents Live and Dead (percent oven-dry weight)

Species	Live: Foliage	0-¼"	¼-1"	1"+	Dead: 1HR	10 HR	100 HR
big sagebrush	84				5	5	5
Utah snowberry	66						
Utah serviceberry	72						
green rabbitbrush	64						
gray rabbitbrush	112						
antelope bitterbrush	66						

Soil Moisture: - % at - cm depth.

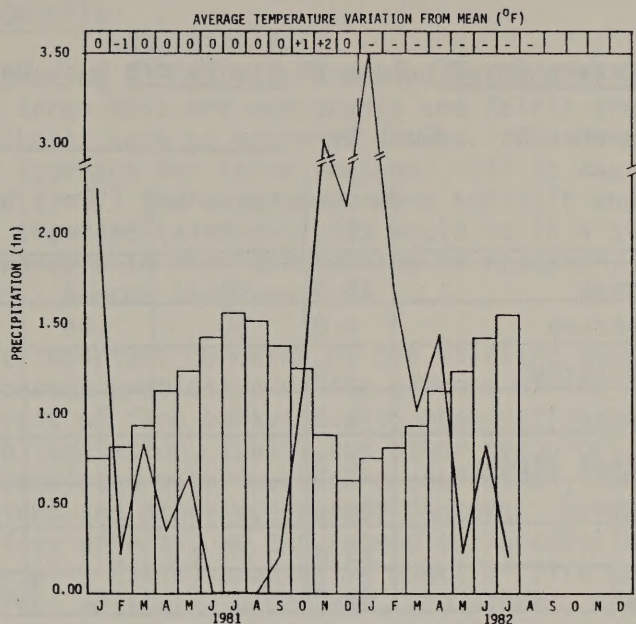


Figure 3. Precipitation and temperature data for Carson site, elevation 6,600 feet. (Weather observations taken in Carson City, NV.) Mean monthly precipitation ⌐¬, 1981-1982 precipitation ——, and average monthly temperature variation from the mean +/-.

Soils in this area are of the Verdico-Uhaldi-Springmeyer association. Burns were conducted on soils of the Springmeyer series, very deep, well-drained, and formed on mixed alluvium. It is a member of the fine-loamy mixed mesic family of Aridic Argixerolls and is found on alluvial fans and valley bottoms. The surface is a brown gravelly loam.

Burning conditions for Carson burns are listed in Table 5.

Table 5. Summary of Burning Conditions for Carson Burns.

I. Site

A. Location Carson Cty,NV; Burn ID Blocks A/B, Blocks C/D; Burn Date 8/19/81, 8/20/81.

B. Preburn Vegetation Fuel Type ________ Age ____ years

Species	Cover (%)	Avg. Ht. (cm)	Fuel Loading (T/A) Foliage	1 HR	10 HR	100 HR
big sagebrush	28.0	80	.27	.39	.70	.94
gray horsebrush	4.0	50	.06	.22	.06	.01
green rabbitbrush	1.0					
desert peach	1.0					
standing dead shrubs	8.0	75		.62	.50	
grass*/forbs	trace					
litter	12.0					
bare ground	46.0		Total Loading : 3.77			

64 cm Fuelbed Depth (80% average)

C. Topography: Elevation 6,600 Ft; Slope 5 %; Aspect SW ; Position on slope flat valley bottom.

II. Environment (A/B) (C/D)

A. Time 1130/1330 Season late summer

B. Weather: Air Temperature 74/78, 76/82 °F; Relative Humidity 35/27, 18/16 %

Wind Speed Minimum 6/10, 10/10 mph, Maximum 8/12, 12/12 mph, Average 7/11, 11/11 mph

Wind Direction SW/SW, SW/SW; Slope Degrees 0/0, 0/0 (0-360°); instrument Ht. 8 Ft.

C. Moisture Contents Live and Dead (percent oven-dry weight)

Species	Live: Foliage	0-¼"	¼-1"	1"+	Dead: 1HR	10 HR	100 HR
big sagebrush	67	30	28	11	5	5	
antelope bitterbrush	88						
gray horsebrush	50		22				
pinyon pine	127	92					
desert peach	116						

Soil Moisture: 2 % at 15 cm depth.

*Great Basin wildrye.

II. GUIDING CONCEPTS

Rothermel and Deeming (1980) have proposed methods of describing fire behavior using terms that are measurable and fairly predictable in uniform and porous fuelbeds, such as grass or shrubs. The Nevada State Office selected their approach for three reasons: (1) it was applicable to western Great Basin fuels, (2) the data needs were explicit and methods for collection clear, and (3) the results of analysis would be in a standard, quantitative form, linking workers in fire disciplines of research, testing, and management with a common language.

One of the most important concerns of the wildland manager's dealings with fire is the accurate prediction of its effects on the land resource. By including analysis of fire behavior with observation and documentation of fire effects on vegetation, fuels, and other resources, these effects can, over time, be predicted with reasonable confidence, taking into account burning conditions and other ecological factors. By correlating fire behavior with fire effects, we can extend our prediction capability by applying Rothermel's (1972) predictive model of fire behavior. Given inputs of fuel type, fuel moisture, windspeed, and others, the model returns fire behavior descriptors such as flame length, fire intensity and rate-of-spread. These, in turn, are then correlated with fire effects.

For example, a land manager learns, after observing several wildfires or prescribed burns, that a certain flame length and rate-of-spread (fire behavior) results in nearly complete removal of sagebrush cover (fire effect). With a fire model, the manager can find the fuel moisture, windspeed, and other factors (burning conditions) that generate the kind of fire behavior that, in turn, produces a desired effect.

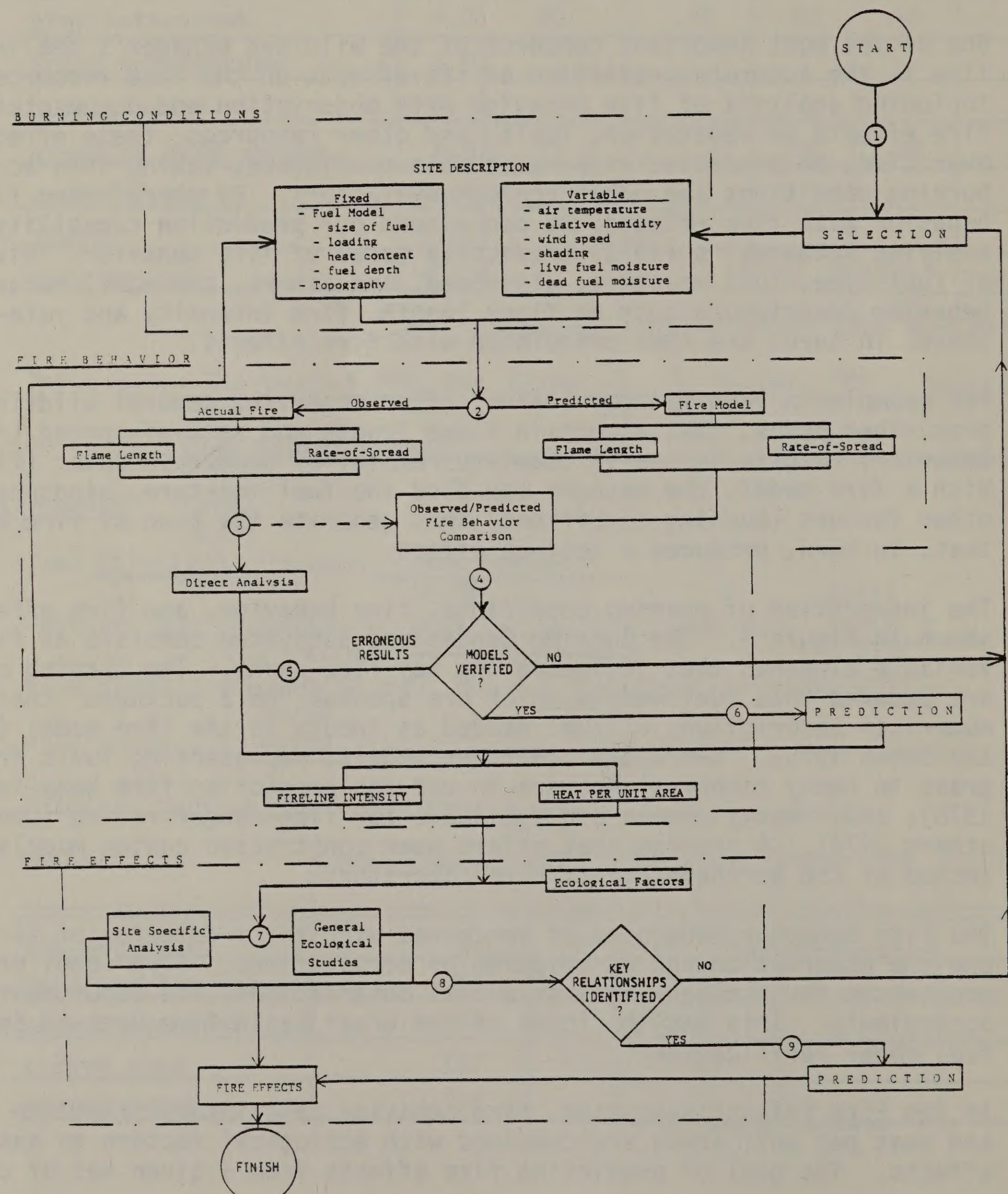
The integration of burning conditions, fire behavior, and fire effects is shown in Figure 4. The Burning Conditions subsystem consists of fixed and variable elements that influence the way fire burns. The burning conditions are entered into fuel models which are special "data packages" that contain numerical descriptions of fuel needed as inputs to the fire model (Deeming and Brown 1975). Currently, thirteen models, representing fuels from short grass to heavy timber slash, are in use for predicting fire behavior (Albini 1976); and, twenty models are available for fire-danger rating (Deeming and others 1978). A program that offers user constructed custom models is being tested at the Northern Forest Fire Laboratory.

The Fire Behavior subsystem is concerned with the prediction of fire behavior and the observation and description of actual fires. Fire model predictions are tested for accuracy against actual observations, and adjustments are made accordingly. This was the focus of the Great Basin Fire Rate-of-Spread Study, fuel model verification.

In the Fire Effects subsystem, fire behavior descriptors (fireline intensity and heat per unit area) are combined with ecological factors to analyze fire effects. The goal of predicting fire effects from a given set of burning

conditions is achieved by first predicting the potential fire behavior, then by assessing the impact of that fire behavior plus other ecological factors on the final outcome. Numbered circles in Figure 4 represent key steps in the sequence.

Figure 4. Information flow for predicting fire effects.



Step 1 consists of selecting the fuel model burning conditions under which a fire will be carried out, or in the case of a wildfire, the conditions under which a fire is observed to be burning. In planned fires, this is referred to as the burning prescription -- a set of variables whose values must be within a specified range before ignition can occur. When a manager is inexperienced in a particular kind of burning, the prescription may only define conditions that will prevent extreme fire behavior from occurring. After executing several similar successful operations, confidence will develop, and experience will lead to refinement of the prescriptions to achieve more specific objectives. The reader is referred to in-depth coverage of this topic (Fischer 1978, Martin and others 1978, Green 1981).

In Step 2, the selected burning conditions set the stage for ignition of an actual fire (Observed), as well as provide inputs for the fire model (Rothermel 1972), which then returns fire behavior predictions (Predicted). Next, the actual fire observations can be converted into quantitative fire behavior descriptors (discussed below) either for direct analysis of that particular fire; or, as Step 3 indicates, these actual parameters can be compared with predicted ones from the fire model.

Depending on the model accuracy required, the cycle of selecting burning conditions, making fire model inputs, igniting actual fires, and comparing observed and predicted parameters is repeated a number of times until the answer to the question in Step 4 is YES. Prediction of fire behavior, given specific burning conditions, is then possible (Step 6). If the results in Step 4 are erroneous, a new fuel model will have to be selected (Step 5).

In Step 7, the fire behavior information is combined with other ecological factors, such as weather, soils characteristics - in short, any factor related to fire, to account for the observed fire effects. Here, as in Step 3, there is again the option to bypass analysis for prediction purposes, and instead to concentrate on site specific information. However, this route still offers the opportunity for input of the specifics to general ecological studies, which can be geared to address Step 8. For example, suppose the objective of a prescribed burn is fuel hazard reduction. Few key relationships exist and little, if any, ecological information is necessary to evaluate the effectiveness of a particular fire behavior in reducing fuel loading. However, should the manager also require a forecast of postfire vegetation potential, the same fire behavior-fuel consumption data can be applied to analysis of seedbed preparation, nutrient budget studies, or other fire-related subjects.

The key relationships referred to in Step 8 are those that exist between fire behavior, ecological factors, and resulting fire effects. To the extent that the interactions of the plant community with its environment are understood and reasonably predictable, the final Step 9 allows prediction of fire effects. It must be pointed out, however, that many of the "interactions" occurring in a plant community are subject to the element of chance, like rainfall. In these situations the manager must perceive that a single fire effects outline may be inadequate. A set of alternative outcomes, each

addressing combinations of possible events, would be more realistic. One could predict, for example, that with complete removal of sagebrush cover forb production would be increased a certain percentage over unburned areas if the following year was wetter than normal; but this increase would be less, or even absent, if a drought year ensued.

In summary, predicting fire effects is not a simple task. Fire alters in some way nearly every component of the environment. There are no easy formulas. The accuracy of any fire effects forecast depends on the quality and quantity of data available concerning natural communities, burning conditions, and fire behavior predictions. It is important that every effort be made to apply consistent and objective techniques in the study of fire and its effects - be it on a one-acre prescribed burn or on wildfires covering entire watersheds.

III. METHODS

A. Plant Responses

Several individuals of shrub and grass species common in Great Basin communities were photographed and marked with numbered metal tags prior to burning. Prefire measurements, for the shrubs, included phenological stage, crown dimensions (height and diameter), a visual estimate of dead crown volume (percent volume), basal diameter, litter depth, and a surrounding fuel rating in three classes: fuel at distances greater than one meter, fuels at less than one meter, and fuels actually in contact with the tagged plant. Perennial bunchgrasses were measured for total height, basal area, litter depth, and their phenological stage was recorded. The small sample sizes of individual species were a compromise, given the number of species observed and the time available for sampling. Percent cover and species composition were sampled with line intercept transects (Canfield 1941). This method was modified from an overlapping to a non-overlapping inventory since it was primarily used for biomass determination. Litter weights were obtained by removing the material within a .10m^2 frame, oven-drying, and weighing.

Immediately after the burn, the plants were again photographed, and the degree of shrub consumption was recorded as defoliation, consumption of stemwood in 0 to ¼ inch, ¼ to 1 inch, greater than 1 inch classes, complete consumption, or unburned. Bunchgrasses were noted as defoliated or completely consumed. Ash depths at the bases of plants were measured and color (black, grey, or white) noted. In addition, approximately 20 Tetrazolium tests were run to determine if live tissue was present.

At eleven and twenty-two months following the August 1980, burns, the line transects were resampled to determine species composition change. The conditions of all tagged plants were photographed and recorded as dead, surviving, resprouting, or seedlings present.

B. Fire Behavior: Fireline Intensity and Heat Per Unit Area

Field observations of fire rate-of-spread and flame length were used to assess two different forms of fire intensity: fireline intensity and heat per unit area (Rothermel 1980).

Fireline intensity is calculated from flame lengths in a headfire by the equation:

(1) $\text{Fireline Intensity} = 5.67\ \text{Flame Length}^{2.17}$

where: Fireline Intensity is expressed as a rate of heat energy released by each foot along the edge of an advancing fire front (BTU/ft/sec) (Byram 1959). Flame Length is the distance (feet) from the flame tip to its base, midway in the flaming zone of the fuelbed (see Figure 5).

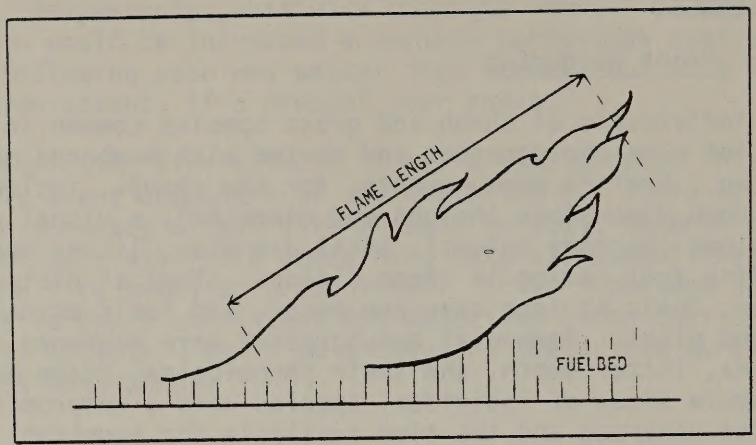


Figure 5. Flame Length Diagram.

Heat per unit area relates the total amount of energy released in the flaming zone by burning a unit area of a given fuelbed. It is obtained by dividing the fireline intensity by the fire's rate of forward spread:

$$(2)\ \text{Heat Per Unit Area } (\text{BTU/ft}^2) = \frac{60 \text{ Fireline Intensity (BTU/ft/sec)}}{\text{Rate-of-Spread (ft/min)}}$$

Flame lengths were estimated by two methods: (1) direct observation, and (2) infrared photographs taken during the burn with reference placards (Britton and others 1977). Fire rate-of-spread was measured by timing the fire's advance over a known distance. The line transects used for vegetation sampling also served as baselines for registering fire behavior observations with the locations of the tagged plants.

1. Fire Temperatures

Maximum temperatures were estimated using heat-sensitive lacquers (Tempilaq) painted on metal strips placed at various positions within plant crowns, at the soil surface, and below ground at 1 and 2 cm. This technique was discontinued in 1981 due to the difficulty in obtaining accurate readings and because of the limited information provided given the time expended.

C. Burning Conditions

Burning conditions are defined as those factors which influence fire behavior, namely the fuels and topography of the site, weather, and fuel moistures prevailing at the time of the burn.

1. Fuels

For study burns conducted in 1980, fuel loadings were estimated by translating percent cover of shrubs into tons per acre via averages of plant sizes and

weights (Range and others 1980). This method was changed in 1981 to more conventional plot-based weighings. This information was used to compare fuel characteristics between sites.

On four randomly placed 10m^2 circular plots, shrubs were cut at ground level, separated, and weighed by size classes: foliage; live stems 0 to ¼ inch, ¼ to 1 inch, and greater than 1 inch; and dead stems 0 to ¼ inch and greater than 1 inch. The entire crown of a shrub was sampled if the base of the plant fell within the plot. Live and dead fuel moistures were determined with an automatic weight loss type moisture analyzer, and the values obtained were used to correct field weights of shrubs to oven-dry weights. These data and other burning conditions are summarized in Tables 1 through 5. Note that the column headings 1-, 10-, and 100-hr corresponding to 0 to ¼ inch, ¼ to 1 inch, and greater than 1 inch stem sizes normally associated with dead fuels are also used for the live stemwood. Measurement of each component of all shrub species was not always possible, so some values are totals only. Height of shrubs was taken as the perpendicular distance from the ground surface to the tallest part of the plant. Fuel bed depth was calculated as 80 percent of the average height of all measured shrubs (Brown 1980; personal communication).

2. Weather

Air temperature and relative humidity were measured with hand-held devices provided in "belt weather kits." For the 1981 burns, a continuous recording type unit was used in addition to hand-held devices. Wind measurements were made with both continuous recording and held-held type meters throughout the study. Weather data may be found in Tables 1 through 5.

IV. INTERPRETATION

It is important to clarify what is meant by "Fireline Intensity" and "Heat per Unit Area," because, until now, no fire descriptors were defined or understood as measures of fire intensity (Albini 1976). Technically, the term "intensity" implies some measure of energy transmission. But fire workers and researchers have used "intensity" to describe many different aspects of fire behavior and effects such as peak flame temperature, maximum soil temperature, degree of fuel consumption, etc. "Fireline Intensity" is commonly used to describe wildland fire because with its good correlation with flame length, it represents what most people seem to visualize when they speak loosely of fire "intensity." It has been useful as a fire suppression term because flame length directly influences the radiated and convected heat firefighters are exposed to on the line.

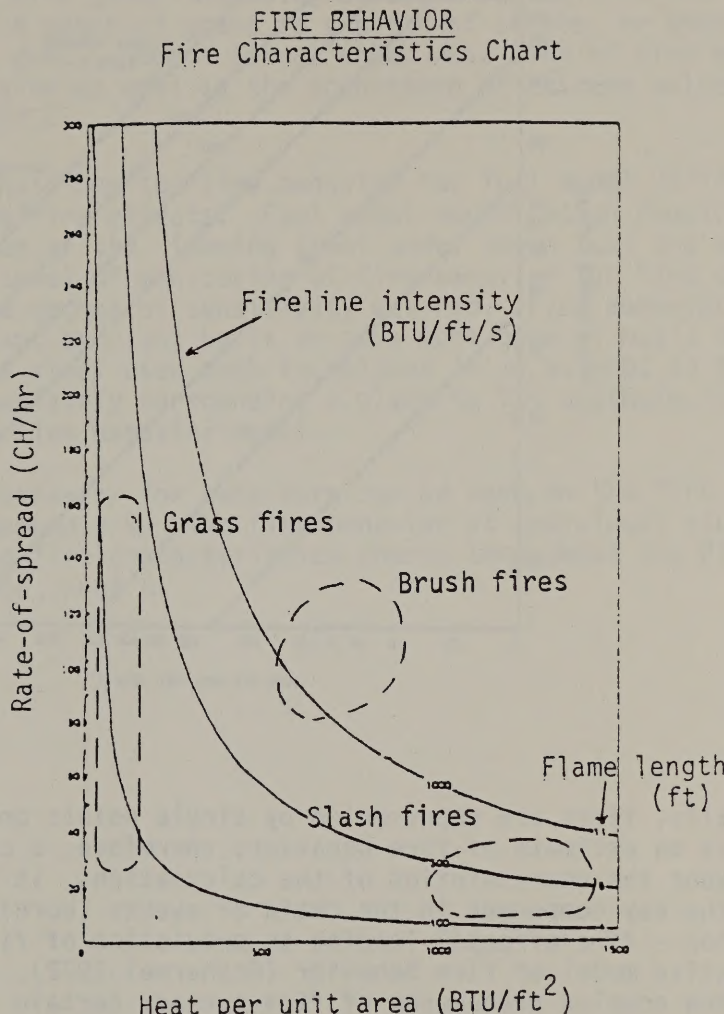
Heat per unit area is a rough measure of the impact a fire has on a site at the location of the unit area of fuel burned. Since wildland fuels all release about the same amount of heat when burned (8000 BTU per pound), the total heat released by burning relates well to the amount of fuel consumed. In addition, heat per unit area is an indicator of the amount of heat that is transferred to the soil during a fire. For example, in equation (2) we see that for a given fireline intensity (flame length) the lower the rate-of-spread, the longer a flaming zone "resides" over a unit area, causing more fuel to be consumed, and more heat to be released there. Such information would be useful in determining fire impact to fragile desert soils, which have most of their soil organic matter near the surface.

A. The Fire Characteristics Chart

The fire behavior terms discussed above have definite meanings and interpretations, but they have not been well understood partially because they evolved from sets of equations and a variety of different units. The fire characteristics chart (Andrews and Rothermel in preparation) was developed to aid interpretation of numbers describing fire behavior. The chart (Figure 6) displays four important fire characteristics -- rate-of-spread, heat per unit area, flame length, and fireline intensity -- graphed as a single point. A fire's rate-of-spread is plotted on the vertical axis and its heat per unit area is on the horizontal axis. The curved lines represent fireline intensity and flame length.

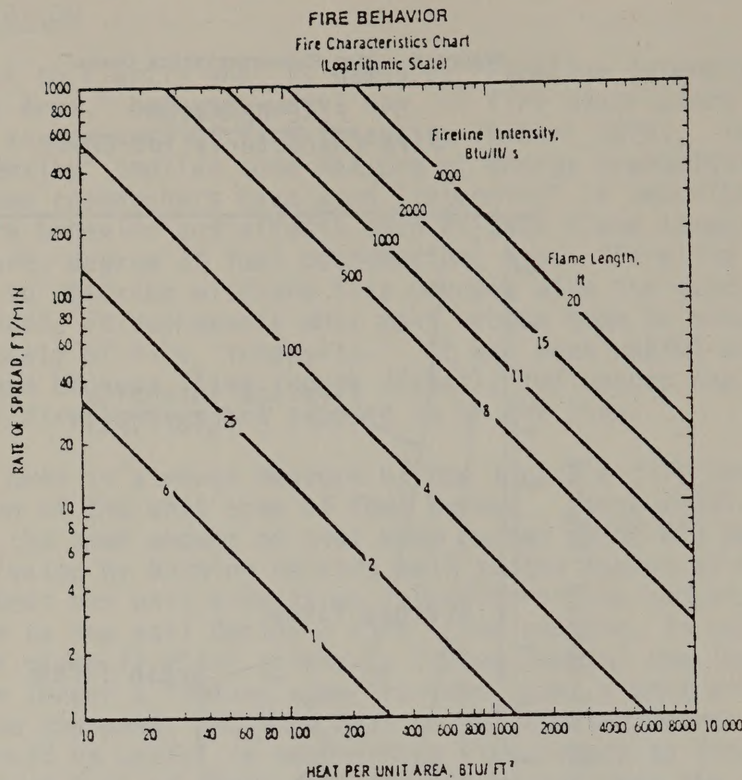
The position of a plotted point on the graph indicates the severity of a fire in two ways. If heat per unit area is taken as the measure of severity, as in fire impact on soil or in fuel hazard reduction, then fires plotted further to the right are more severe. If rate-of-spread is the critical factor, as in fire control situations, points highest on the graph are of great concern. For example, a fast-spreading grass fire of low intensity would plot near the vertical axis, whereas a high intensity, slow-moving slash fire would lie close to the horizontal axis. The further a point lies to the upper right of the graph's origin, the more severe the fire. In heavy chaparral, for instance, fires generate high intensities and rapid spread, and thus are plotted near the center of the graph, far from the origin.

Figure 6. Fire Characteristics Chart.



Not all fires can be plotted on a chart like Figure 6. Some fires have values beyond its scales. To deal with the levels of intensity and rates-of-spread often encountered in sagebrush fuels, a chart with logarithmic scales can be used (Figure 7). The diagonal lines are analogous to the curved lines of Figure 6. Note that the axes are logarithmic, not linear, and more care is needed to interpret the positions of points than on the standard chart. For consistency with units in field observation, the rate-of-spread scale in Figure 7 was changed from units of chains per hour (Figure 6) to units of feet per minute. The difference between the two units is about 10 percent. Unless fires have a low rate-of-spread, no significant change in the relative positions of points occurs. Hear per unit area units are unchanged.

Figure 7. Expanded Fire Characteristics Chart.



Generally, fires are represented by single points on the chart, but this is only an estimate of fire behavior; therefore, a circle would more truly represent the uncertainties of the calculation. It must be remembered that the key component in the chain of events (burning conditions - fire behavior - fire effects) leading to prediction of fire effects is the predictive model of fire behavior (Rothermel 1972). For the model to deal with the complex phenomenon of fire spread, certain simplifying assumptions are made. The most significant of these is that the fire spread is through continuous, uniform fuels, such as a sward of tall grass or an even layer of pine needles. As wildland managers know, this ideal fuelbed rarely occurs over extensive areas in the Great Basin. Patches of shrubs may occur within the grassland, or dense piles of downed wood may be found about the forest floor, causing the fire to flare up as it moves from the uniform fuels into these concentrations. Thus, the more discontinuous or patchy the fuels are, the less accurate the expected of a single output from the fire model, and the larger the plotted circle should be on the fire characteristics chart.

In situations where the fuelbed is a mixture of very different fuels, such as sagebrush-grass, or when the wind is shifting or gusting, a frequency distribution of fireline intensities (flame lengths) and rates-of-spread

is more informative than averaged values (Frandsen and Andrews 1979). This is nothing more than displaying, in bar graph form, the number of observations made of a given intensity or other variable as the fire moves, for example, from a patch of grass to a patch of shrubs, or when flames flare up due to a gust. Such a format shows what kind of fire behavior prevailed on the site as well as the occurrence of extreme values. See Figures 13.1 and 13.2.

Observers may wish to monitor fire behavior for fuel model verification or for determining fire effects. Fuel model verification requires an average observation of the flamming front under known fuel and weather conditions. The level of monitoring of fire behavior for fire effects will depend on the degree of sensitivity desired. Fire behavior can be monitored on a plant by plant basis or on a more general basis over an entire site. This study used both techniques in an attempt to tie the fire behavior immediately surrounding a plant to its postburn response and to verify the fire behavior model.

The average fire behavior for each burn can be seen on the fire characteristics chart in Appendix C. The fire behavior at individual study plants can be seen on the fire characteristics charts throughout the Plant Response discussion, part C.

V. RESULTS AND DISCUSSION

A. General Fire Behavior

Observations of flame lengths and rates-of-spread are summarized for each burn on fire characteristics charts (Figures 8 to 13). Each run of the fire on which rate-of-spread was measured was associated with a particular flame length. These individual pairs of measurements are represented by the circles. The closer a point is to the upper right, the more severe the fire. Refer to Tables 1 to 5 to find the burning conditions responsible for the fires' behavior.

Elko Burns 1 and 2, and Ely Burn 2 were marked by erratic fire behavior (Figures 8, 9, and 11). Although fuels were uniform over a distance of about 30 feet, wind speed and direction changes were so rapid that the "model" fire (steady state) never occurred. At Elko, burning within the narrow drainages, with a heavy load of find fuels in the shrub understory, accounts for these results. The angle of the slope relative to the wind at Ely Burn 2 and sequences of gusts and lulls were factors responsible for the lack of steady state fire on that site. Note carefully that because of the logarithmic scale on the charts, significant variation of fire behavior is displayed, despite apparent clustering of the observations.

Burn 1 conducted at Ely permitted the best data collection of all. Although the circles in Figure 10 are widely scattered, each level of intensity can be associated with a particular zone within the burn plot. For this reason, individual fire characteristics charts accompany discussion of burn results for tagged plants located in the zones. (See Figures 19 to 25, under Plant Responses - Expectations and Results.)

Collection of numerous data points was possible at the Carson site because of small burn blocks and easy access around their perimeters. The reader should recognize, however, that the quantity of data does not necessarily correlate with quality. On these burns, the sites came close to meeting the assumptions made by the fire model -- uniform shrub heights and spacing, little or no fine fuels in the understory, flat topography, steady wind direction -- except wind speed. Fluctuation of this critical factor is evident in the scatter of circles on Figures 12 and 13. Other burning conditions were nearly equal for all the burns. Disregarding the outlying circles on burns A and C, the data show that the four burns were of similar intensity because each burn was subjected to similar ranges and fluctuations of wind speeds. However, no clear trend of wind influence is discernable between burns. It can only be assumed that the upper ranges (12 to 15 mph) of midflame winds were responsible for the upper ranges of fire intensity and rate-of-spread. Similarly, one would expect the fire values in the lower left of the chart to be due to wind lulls down to four to six mph. Figures 13.1 and 13.2 display the overall fire behavior of the Carson burns.

Appendix C displayes the fire characteristics of all test burns on one chart.

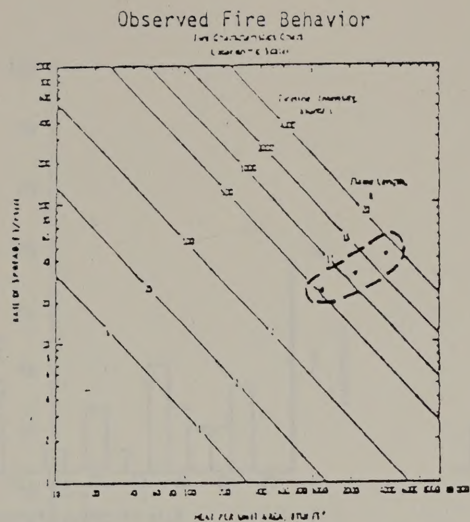


Figure 8. Elko Burn 1 Observed Fire Behavior.

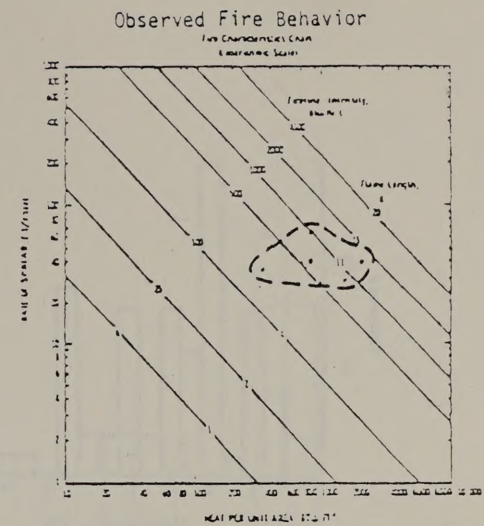


Figure 9. Elko Burn 2 Observed Fire Behavior.

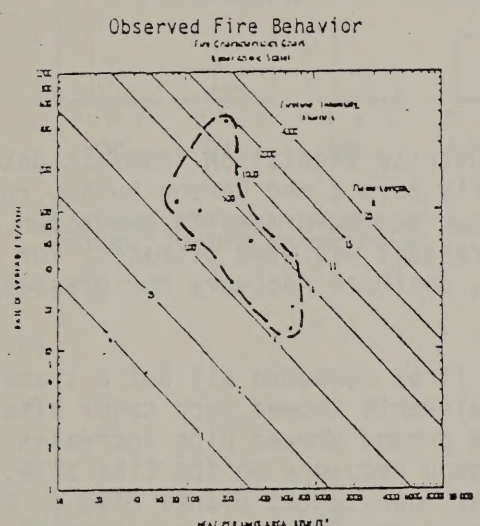


Figure 10. Ely Burn 1 Observed Fire Behavior.

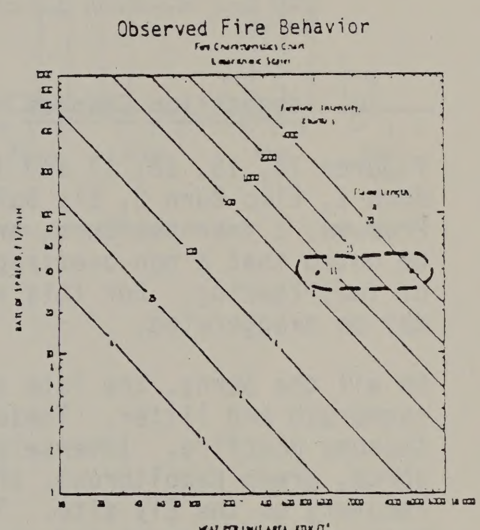


Figure 11. Ely Burn 2 Observed Fire Behavior.

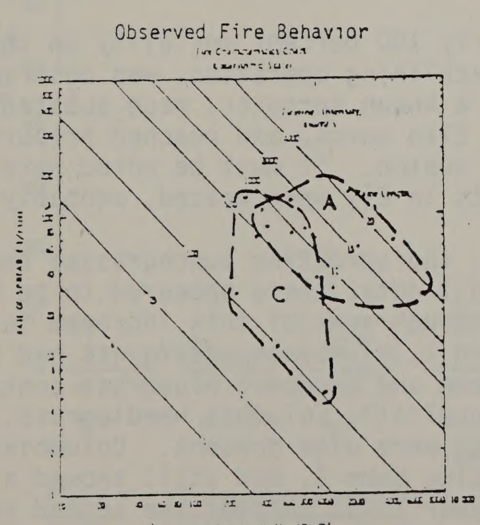


Figure 12. Carson Burns A and C Observed Fire Behavior.

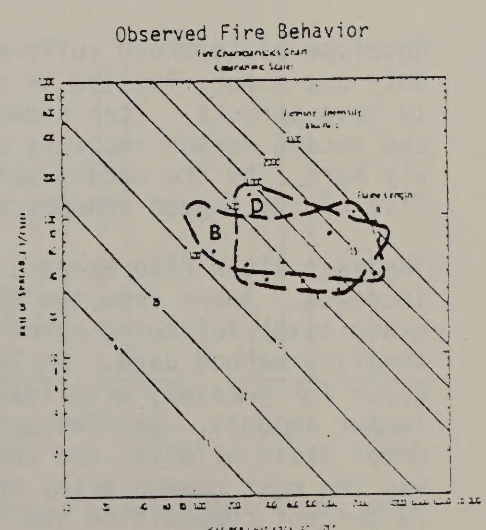


Figure 13. Carson Burns B and D Observed Fire Behavior.

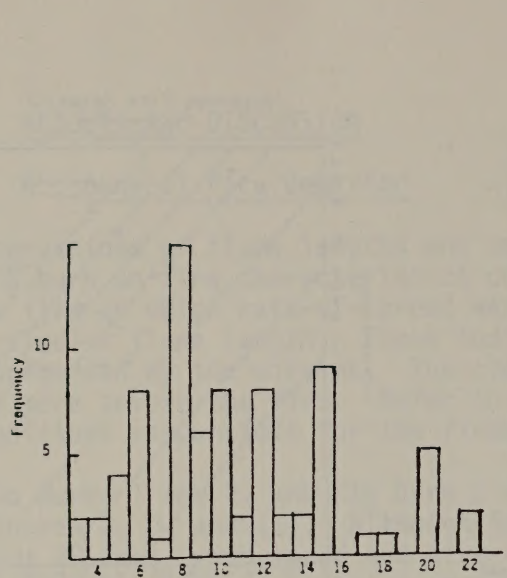


Figure 13.1 Frequency distribution of flame lengths on Carson burns. Maximum winds 12-15 mph, 6 ft. above tops of shrubs.

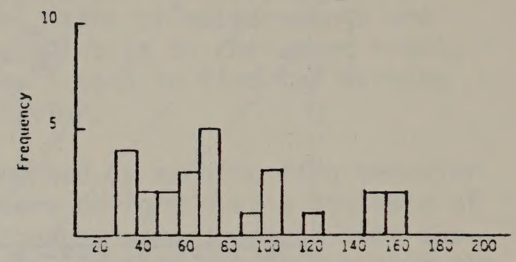


Figure 13.2 Frequency distributions of fire rates of spread on Carson burns.

B. Vegetation Changes

Figures 14, 15, 16, 17 and 18 illustrate vegetation transect data for Elko Burn 1, Elko Burn 2, Ely Burn 1, Ely Burn 2 and Carson burns, respectively. Preburn, 1 year postburn, and 2 year postburn results are shown. It should be noted that a non-overlapping transect was used primarily for determination of fuel loading. For this reason, postburn recovery for grasses and forbs may be exaggerated.

On all the burns, the late summer fires consumed all but a trace of big sagebrush and litter. These two elements showed zero cover after two seasons postfire. Inversely, bare ground showed high increases. The sprouting shrub, green rabbitbrush, showed good recovery on the Elko site; but poor recovery on the Ely site. Three of four tagged plants died on Ely 1 while both on Ely 2 resprouted, even though the fire was more intense on the second burn. The three plants tagged on the Elko burns were sprouting vigorously.

Antelope bitterbrush suffered nearly 100 percent mortality on the Ely burns. Only one shrub, located in the blacklining operation, was observed in 1982 to have sprouts. Utah snowberry, a known sprouter, made substantial first and second season recovery on the Elko burns, and reached preburn levels on Ely Burn 2 by the second postburn season. It must be noted here that all five of the tagged snowberry plants in Ely were grazed, probably by rabbits.

The year after Elko Burns 1 and 2, the sprouting bunchgrasses showed a large increase. Apart from the Ely Burn 1 data, there appeared to be increased grass cover following burning, although some of this increase is due to the sampling method used. On Elko Burn 1, bluebunch wheatgrass had the most cover for grasses, with Idaho fescue and Sandberg bluegrass contributing lesser amounts. Bottlebrush squirreltail, Columbia needlegrass, oniongrass, Great Basin wildrye, and cheatgrass were also present. Columbia needlegrass was the most common grass on the Elko Burn 2, but still showed a decline from 79 percent composition the first year to 53 percent the second year. Grasses that increased in value were Idaho fescue, Sandberg bluegrass and oniongrass.

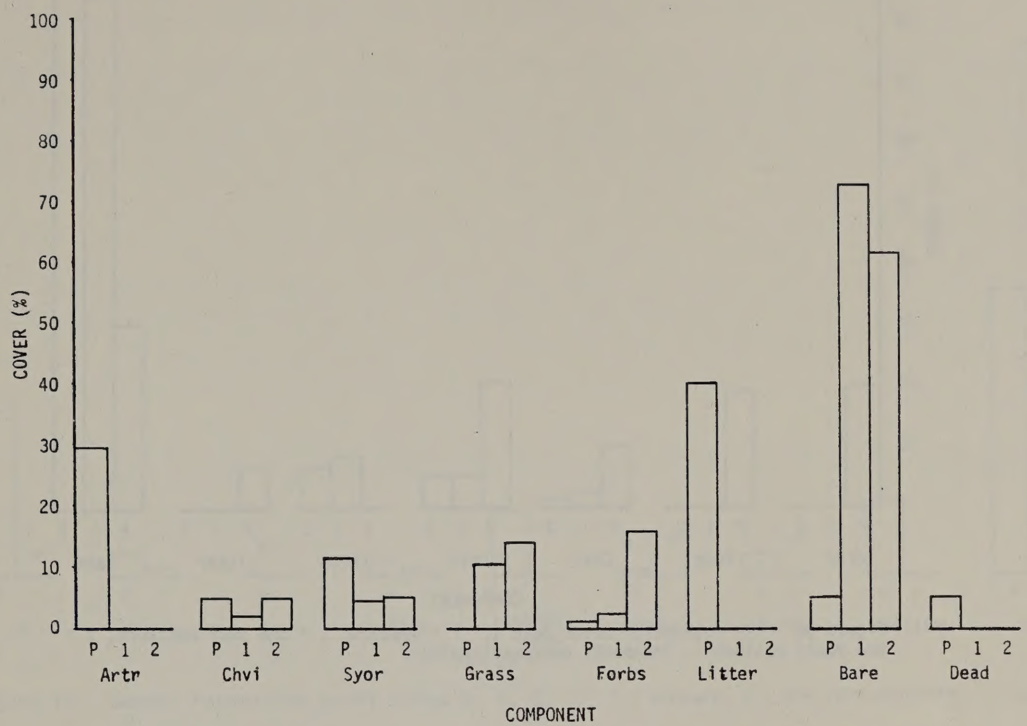


Figure 14. Elko vegetation cover Burn 1. P = preburn, 1 = one year postburn, 2 = two years postburn. Transects non-overlapping.

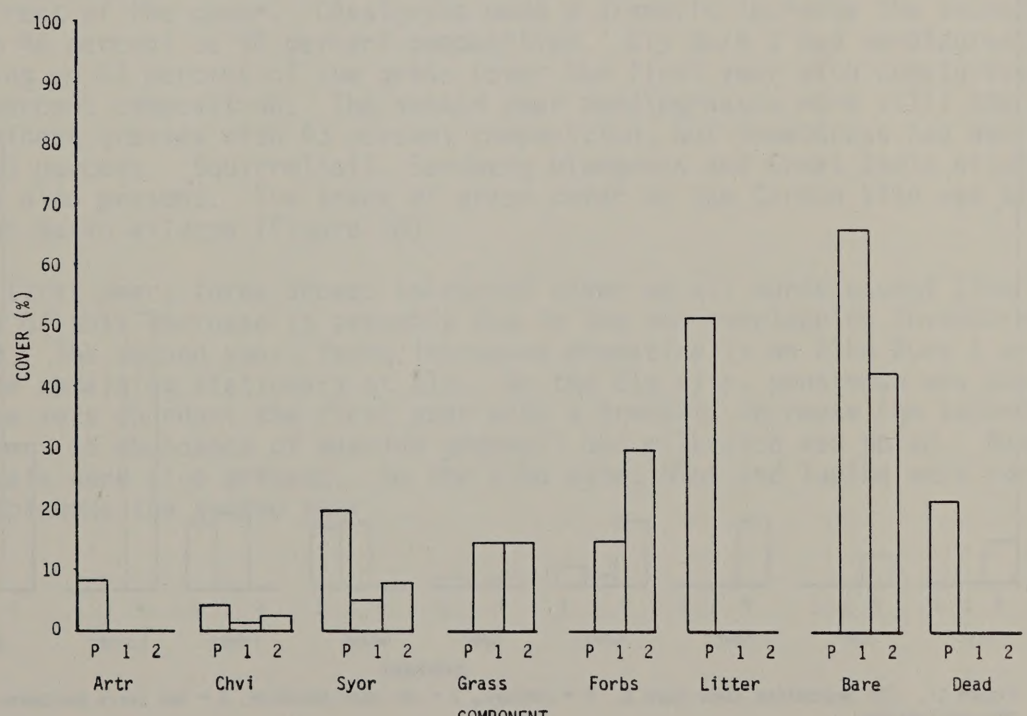


Figure 15. Elko vegetation cover Burn 2. P = preburn, 1 = one year postburn, 2 = two years postburn. Transects non-overlapping.

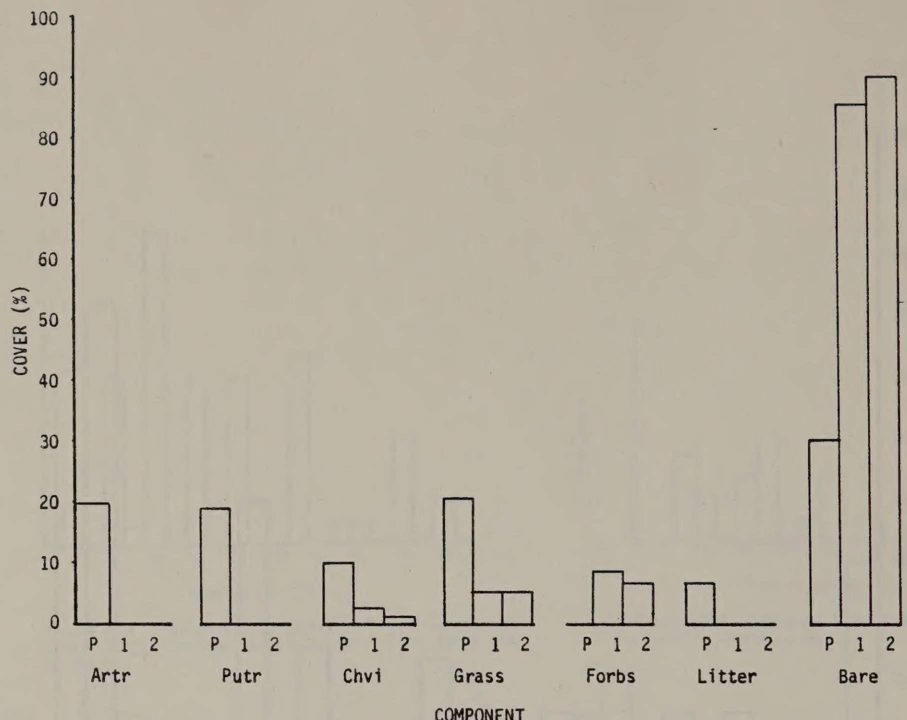


Figure 16. Ely vegetation cover Burn 1. P = preburn, 1 = one year postburn, 2 = two years postburn. Transects non-overlapping.

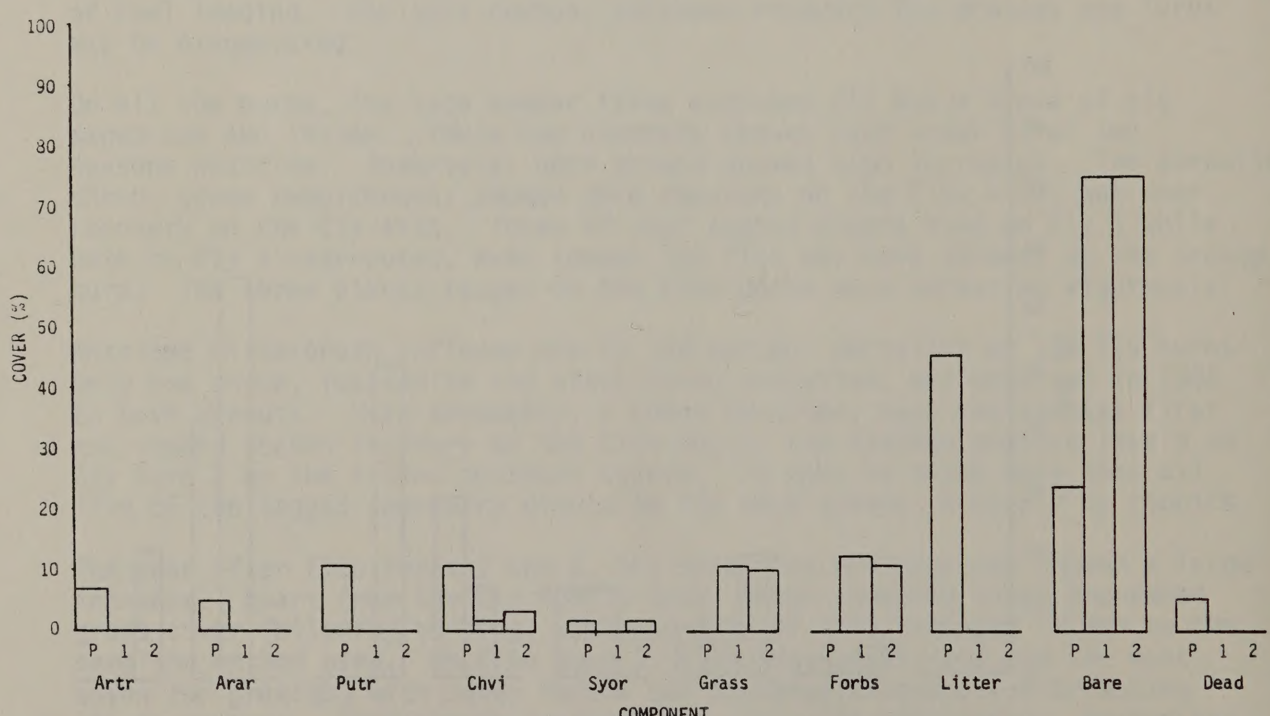


Figure 17. Ely vegetation cover Burn 2. P = preburn, 1 = one year postburn, 2 = two years postburn. Transects non-overlapping.

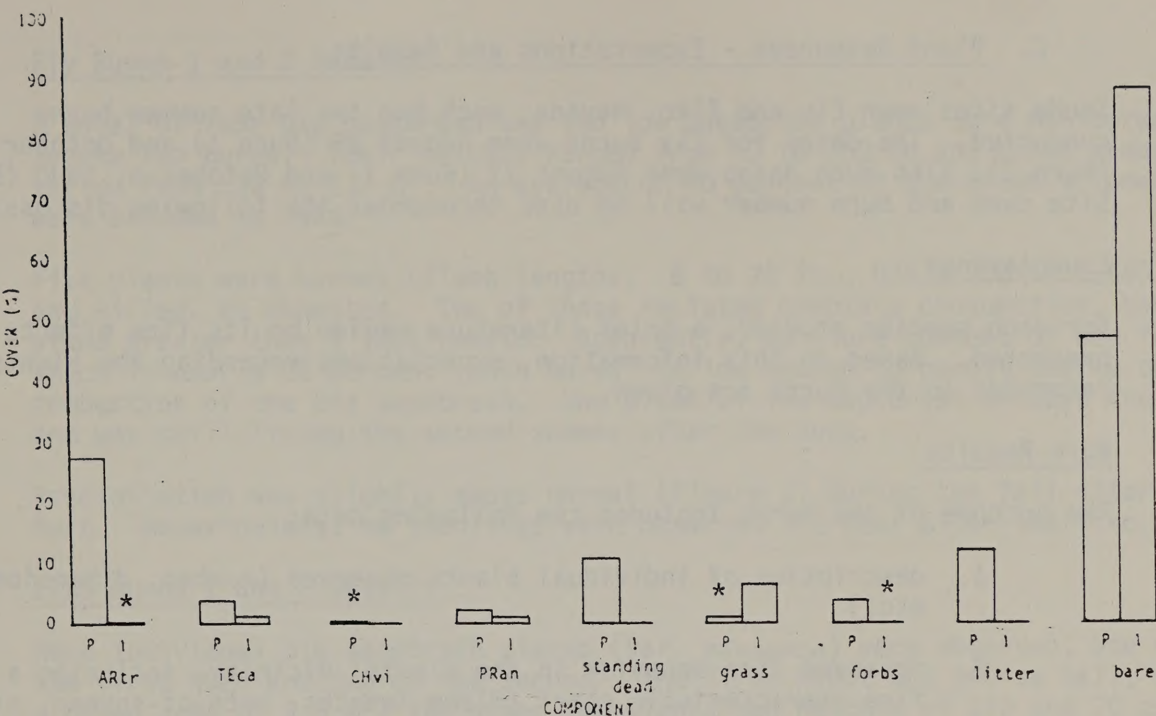


Figure 18. Carson Vegetation Cover Burns A, B, C, D. P = preburn, 1 = one year postburn. *<0.5%
Transects non-overlapping.

Cheatgrass contributed nearly half the grass cover the first year after burning the Ely 1 site. Needlegrasses, bluegrass, and Idaho fescue made up the rest of the cover. Cheatgrass made a dramatic increase the second year from 46 percent to 98 percent composition. Ely Burn 2 had needlegrasses making up 53 percent of the grass cover the first year with cheatgrass having 33 percent composition. The second year needlegrasses were still the most prominent grasses with 43 percent composition, but cheatgrass had declined to 13 percent. Squirreltail, Sandberg bluegrass and Great Basin wildrye were also present. The trace of grass cover on the Carson site was all Great Basin wildrye (Figure 18).

The first year, forbs showed increased cover on all burns except Elko Burn 1. Some of this increase is probably due to the non-overlapping inventory method used. The second year, forbs increased dramatically on Elko Burn 1 and 2 while remaining stationary at Ely. On the Ely site, penstemon was observed to be very abundant the first year with a dramatic decrease the second year. Rather, an abundance of wayside gromwell and milkvetch was noted. Many weedy annuals were also present. On the Elko site, mint and lupine were very conspicuous the second year.

C. Plant Responses - Expectations and Results

Study sites near Ely and Elko, Nevada, each had two late summer burns conducted. The dates for Ely burns were August 29 (Burn 1) and October 8, 1980 (Burn 2); Elko burn dates were August 27 (Burn 1) and October 6, 1980 (Burn 2). Site name and burn number will be used throughout the following discussion.

Expectations

For each species studied, a brief literature review on its fire effects is presented. Based on this information, expectations regarding the plants' responses to the burns are given.

Burn Results

The outcome of the burns includes the following data:

1. description of individual plants observed (number, dimensions, etc.)
2. observed fire behavior in the plants' vicinity, including a fire characteristic chart (flame lengths, rate-of-spread, etc.)
3. immediate postfire plant condition (consumption class, ash color, etc.); and
4. condition of the plants on the 1981 and 1982 sampling (dead, resprouting, etc.).

1. Big sagebrush (*Artemisia tridentata*) (Artr)

Expectations:

Big sagebrush is highly susceptible to fire injury and does not sprout from the stem or root crown following fire (Blaisdell 1953; Pechanec and others 1954; Johnson and Payne 1968). Differences in recovery rates may be related to season of burn as it affects seed production, summer precipitation, and completeness of burn (Wright and Bailey 1982; Kozlowski and Keller 1966). When perennial grasses and weeds are present, big sagebrush seedlings experience increased difficulty in surviving due to the greater vegetative density and less soil moisture available for germination (Pechanec and others 1954). If a good moisture year occurs shortly after burning, big sagebrush reestablishment can be greatly accelerated (Sneva 1978).

Big sagebrush was expected to be temporarily eliminated from the site due to the intense late summer burn and the timing of comsumption of the pre-flowering buds.

Ely Burns 1 and 2 Results:

A total of four big sagebrush and two low sagebrush plants were monitored in the two burns. Their heights ranged from 60 to 130 cm and crown areas varied from .30 to 1.2 m^2. An average of 50 percent of the crown volumes were assumed as dead.

Five plants were burned (flame lengths: 6 to 20 ft.; H/A = 300 to 5,660 BTU/ft^2) and killed, as expected. Two of these resisted complete consumption, having stems greater than 1 inch remain. Apparently, moisture content of new foliage which is nearly 85 percent (both burns) is low enough to permit nearly complete combustion of the big sagebrush. One plant of low sagebrush escaped the fire and was still living the second summer after the burn.

Precipitation was slightly above normal (Figure 2) during the fall after the burn. Nevertheless, no seedlings were observed one year after the fire.

Elko Burns 1 and 2 Results:

Here individual big sagebrush plants (var. *vaseyana*) were observed, one on the first burn and two on the second. The first plant was 140 cm tall, with a crown area of 2.5 m^2; the other two plants had heights of 140 and 70 cm, with crown areas of 2 and .5 m^2, respectively. Crown volumes contained about 20 percent dead material.

As expected, the plants were killed in the Aguust and October burns. The plant in burn 1 was completely consumed despite the 98 percent moisture content of new foliage. Both plants in burn 2 had stemwood 1 inch in diameter and greater remaining, surpising in view of the 50 percent foliage moisture of these plants. Higher density of surrounding fuel in the burn 1 plant over those of burn 2 may account for these results. Figures 8 and 9 show the general range of fire behavior characteristics for each burn.

Precipitation records indicate a fall season drier than normal for the Elko site (Figure 1). This, combined with the destruction of the big sagebrush flowering buds in the late season burn and the fact that no seedlings were observed in July of 1980, indicates that reestablishment may be delayed for a few years.

2. Bitterbrush (*Purshia tridentata*) (Putr)

Antelope bitterbrush commonly suffers high mortality following fire, especially in the western Great Basin (Billings 1952; Nord 1965; Klebenow and others 1976). Sprouting ability of the columnar growth form, present on the Ely site, is more dependent on fire intensity and soil moisture than that of the decumbent growth form (Monson and Christensen 1975). Hence, the midsummer burn, with low fuel moistures generating elevated fire intensities, combined with dry soils, was expected to kill most of the antelope bitterbrush plants on the site (Blaisdell 1953; Blaisdell and Mueggler 1956; Pechanec and others 1954).

Natural regeneration was anticipated from rodent-cached seeds (Klebenow and others 1976), and seedlings were expected to survive despite high surface temperatures on the newly bared soil (Ferguson 1972).

Carson Burns:

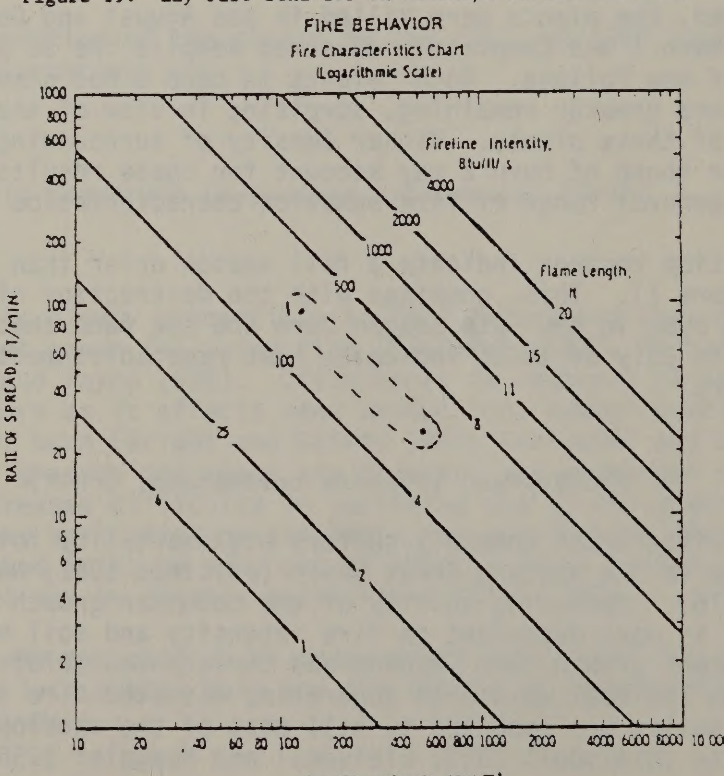
One year postburn, many big sagebrush seedlings were observed. Although the site was burned in August with near complete removal of litter, the seedlings were able to reestablish. This response is most likely related to a year of above normal precipitation.

Ely Burn 1 Results:

Five mature antelope bitterbrush plants were tagged prior to burning on August 11 and August 29, 1980. These ranged from 60 to 120 cm in height and 10 to 40 percent dead crown volume (visual estimate). The plants were in fruiting stage at the time of the burn.

A headfire burned the plants with their foliage moisture at 96 percent and with soil moisture at 6 percent (15 cm depth). Flame lengths averaged 6 feet with rates-of-spread ranging from 25 to 100 feet per minute. These values indicate moderate to high fire severity as shown in Figure 19.

Figure 19. Ely Fire Behavior on Antelope bitterbrush Burn 1.



The plants were all defoliated, one from radiation alone; however because of the high foliage moisture content and of the stemwood density, the crowns resisted consumption. Surface condition at the base of the plants ranged from unburned litter to 2 cm of white ash. No green material was observed on the plants, so all plants along the transects were assumed dead 11 months postfire. One untagged plant located in the blacklining operation was observed to be sprouting.

Ely Burn 2 Results:

The three antelope bitterbrush plants observed on the site of the October burn were exposed to over ten times the heat load of the plants in the July burn. Besides killing the plants, the fire consumed stemwood up to ¼ inch in diameter with fireline intensity reaching 3,770 BTU/ft/sec and heat per unit area values of 5,660 BTU/ft (flame lengths 6 to 20 ft, rate-of-spread 40 ft/min). No seedlings were observed upon revisiting the site in 1981 and 1982.

Elko Burns 1 and 2 Results:

No antelope bitterbrush was found on the Elko site.

3. Green rabbitbrush (*Chrysothamnus viscidiflorus*) (Chvi)

Expectations

Following fire, green rabbitbrush sprouts from roots and increases in density through seedling establishment (Young and Evans 1974). Largely dependent on the plant stage at the time of burn, a green rabbitbrush plant may or may not have already deposited seed. This will influence the time required for plant reestablishment. If a fire occurs prior to seed dispersal, plant reestablishment may be slow during the first three years. Beyond the second year seed production will accelerate resulting in greater plant density during the third year (Blaisdell 1953). The literature reviewed did not address the effects of varying fire intensity and fluctuations in annual precipitation on green rabbitbrush survival. Nevertheless, the plants were expected to sprout during the year following the fire, produce seed, and by the fourth year to exhibit rapid growth as an even-aged stand.

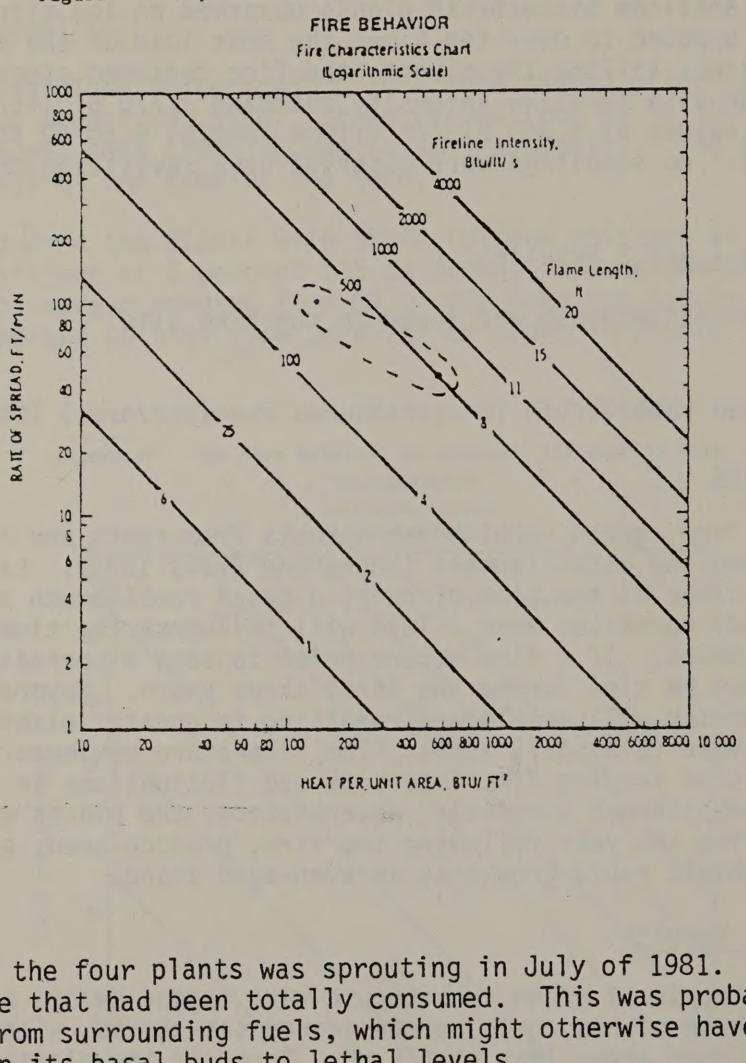
Ely Burn 1 Results:

Four individuals of green rabbitbrush were tagged before burning in late August. These plants could be considered sub-shrubs, with heights of about 40 cm and crown areas less than ¼ m^2. Three of the plants were in a budding stage and one was still vegetative. Litter depths averaged 3 cm at the plant bases.

Rates-of-spread from 25 to 100 ft/min and flames from 6 to 8 feet long were recorded. Three plants were totally consumed by fire with a rate-of-spread less than 50 ft/min. The plant burned by 100 ft/min fire spread had only its

foliage consumed. Although the foliage and twig moisture contents were over 100 percent oven-dry weight, the flammable resins in rabbitbrush leaves permitted high intensity combustion. Crown temperatures reached a maximum of 1,800°F. Soil temperatures were low (150°F at 1 cm, 125° at 2 cm), probably as a result of insulation provided by the litter layer. Figures 10 and 20 display the fire behavior associated with these plants.

Figure 20. Ely Fire Behavior on Green rabbitbrush Burn 1.



Only one of the four plants was sprouting in July of 1981. This plant was one of those that had been totally consumed. This was probably due to its isolation from surrounding fuels, which might otherwise have raised the heat load on its basal buds to lethal levels.

Ely Burn 2 Results:

Two individuals of green rabbitbrush were burned in the October fire while in their flowering stage. The shrubs were between 40 and 50 cm tall, with 1/3 m^2 of crown area each, and litter near 2 cm deep at their bases. Foliage moisture was 66 percent.

Fire impact to the plants consisted of 10 to 20 foot flames corresponding to 840 to 3,770 BTU/ft/sec and heat per unit area from 1,260 to 5,660 BTU/ft^2. The shrubs were not totally consumed, but foliage and stems up to ½ inch had been burned away. Much white ash was present (up to 10 cm), most likely as fallout from surrounding shrub consumption.

Both plants were resprouting when the site was visited in 1981 and 1982. New shoots were about 25 cm long in 1981.

Elko Burn 1 Results:

Only one plant of green rabbitbrush was observed on this burn. Its maximum height was 42 cm and its crown area about .50 m^2. The plant was in full flower.

Foliage and stems less than ¼ inch in diameter were consumed by the fire. Crown and surface temperatures were between 1,200° and 1,500°F. Soil temperatures at 1 and 2 cm were approximately 200°F. (Temperature data based on an average for burn site.)

The plant sprouted during a year in which below normal precipitation occurred. It reached 26 percent of its original height the first year after the burn, and 74 percent by the second year.

Elko Burn 2 Results:

Three individuals of this shrub were selected for observation. Heights were approximately 50 cm and crown areas about .50 m^2. All the plants were past the flowering stage and dormant. Litter depth averaged 2 cm at their bases.

The three green rabbitbrush plants were totally consumed by the burn. One of them did not resprout. From the small sample observed, it is impossible to draw definite conclusions; however, the plant that died was surrounded by more fuel than the other plants which could have resulted in more heat impact to the basal buds. If a longer burnout occurred, there may have been greater penetration of heat into the soil. This, combined with below normal precipitation which followed the burn, could have killed the plant. Of the other two, one had reached 48 percent of its original height by the second year following the burn, the other, 72 percent.

4. Rubber rabbitbrush (*Chrysothamnus nauseosus*) (Chna)

Expectations:

Although rabbitbrushes are usually enhanced by fire, rubber rabbitbrush is an exception to this general response. Robertson and Cords (1957) reported no recovery of this species on two separate burns, one in California and one in Nevada. In contrast, they also record 95 percent recovery on a burn made the following year on the same date. Monsen (personal communication, Wright 1979) concludes that the intensity of the fire is important because most of the sprouting is stem sprouting, not basal or root sprouting.

Initially, a delay will occur in achene production after the burn followed by a season for peak seedling establishment. Information regarding the relation of fire intensity and postburn precipitation with plant sprouting and seed survival were not available in the literature reviewed. Since the plants were burned while in a flowering state, at a time when carbohydrate reserves are low and fire intensity was high, plant survival through stem sprouting was not expected. Seedlings are not anticipated unless seed from outside the study area is transported into the burn or soil-stored seeds germinate.

Ely Burn 1 Results:

No plants of this species were tagged on this burn.

Ely Burn 2 Results:

Two rubber rabbitbrush plants were monitored for fire effects on this burn: one 60 cm tall with .13 m^2 crown area, the other 130 cm tall with .50 m^2 of crown area. Both plants had basal clumps with a diameter of 10 cm and a litter depth of 2 cm.

A fireline intensity of 3,770 BTU/ft/sec (flame lengths 20 ft) had completely consumed one plant, but left branches ½ to 1 inch in diameter on the other. The totally consumed plant was more isolated from surrounding fuels. Both plants had white ash approximately 3 cm deep about their bases.

Neither plant was resprouting on the July 10, 1981, sampling date. Even though foliage moisture was up 112 percent, the extreme fire intensity was probably responsible for this result by removal of a majority of the stemwood sprout sources.

Elko Burn 1 Results:

One plant, 54 cm tall and .23 m^2 in crown area, was selected for observation. Its phenological stage was full flowering and litter surrounding the plant was 4 cm deep.

The rubber rabbitbrush plant was totally consumed by fire and exposed to crown, surface, 1 cm soil, and 2 soil temperatures of 1500°F, 1,500°F, 225°F, and 200°F, respectively. One year postfire observations revealed that the plant resprouted to a maximum height of 8 cm. Rubber rabbitbrush reestablishment by seedlings was not observed on the burn site. Followup observation will be necessary to determine the number of plants that reoccupy the site by seedling establishment and to determine future growth trends.

Elko Burn 2 Results:

No individuals of rubber rabbitbrush were observed on the second burn site.

5. Mountain snowberry (*Symphoricarpos oreophilus*) (Syor)

Expectations:

Vallentine (1971) lists snowberry species as being undamaged by fire. Generally, Utah snowberry is accepted as a sprouter that may be damaged by varying fire intensities (Wright and others 1979). Pechanec (1954) showed that mountain snowberry was undamaged by fire. Depending on precipitation and effective soil moisture following the burn, snowberry plants continue to grow vigorously after resprouting, with complete recovery 15 years after burning (Pechanec and others 1954; Blaisdell 1953).

The mountain snowberry was expected to resprout and grow vigorously on the Elko site until sagebrush cover reestablishes dominance (Blaisdell 1953).

Ely Burn 1 Results:

Two mature mountain snowberry plants were observed in the first burn. They measured 50 and 90 cm in height and had crown areas averaging 1.50 m^2, composed of several stems growing from a tenth square meter of ground surface. The plants were in the seed dispersal stage and averaged 2 cm litter accumulation.

The crowns of these shrubs were fused with those of the surrounding big sagebrush, and despite a fairly high (81 percent) foliage and twig moisture, the mountain snowberry was consumed down to the root crown in both cases. Maximum temperatures of 1,400°F at the soil surface and 1,800°F within the canopy were generated by flames seven feet long and heat per unit area between 400 and 800 BTU/ft^2, as seen in Figure 21. Beneath one plant, maximum soil temperatures reached 300°F at 1 cm and 275°F at 2 cm. White ash, 2 cm deep, was present at the base of the plants immediately after the burn.

In mid-July 1981, both plants were sprouting from the basal root crown. Shoots were over 10 cm long, indicating adequate precipitation occurred postfire (Figure 2). Browsing was evident although the site was fenced.

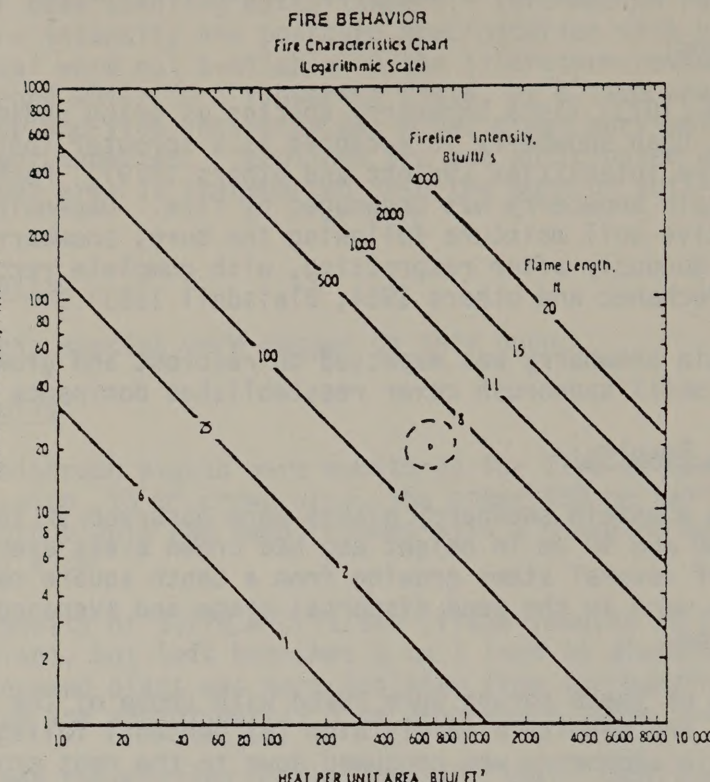
Ely Burn 2 Results:

The three snowberry plants observed on the second burn were larger (120, 120, and 90 cm; crown areas 1.5 to 3.2 m^2, respectively) and more decadent (up to 50 percent dead crown volume) than those found in burn 1. All were in a dormant vegetative stage at the time of the burn with foliage moisture at 66 percent.

Fire swept through the plant crowns at over 40 ft/min with flames 20 feet long (I = 3,770 BTU/ft/sec; Heat/Area = BTU/ft^2).

Two of the plants had foliage and stemwood up to ¼ inch consumed, while the third individual lost only its foliage. This plant had surrounding fuel one meter away, whereas the other two plants had their crowns fused with other shrubs and grasses. White ash was observed at all the plant bases.

Figure 21. Ely Fire Behavior on Mountain snowberry Burn 1.



After one growing season, the three mountain snowberry shrubs were crown sprouting with shoots up to 40 cm long. Signs of browsing, probably by rabbits, were present. The presence of livestock or concentrations of native herbivores (such as rabbits) before and particularly after burning, can completely alter the vegetational responses to fire. Grazers exert selective pressure on certain species, making it difficult to separate changes produced by fire from those caused by grazing (Vogl 1974).

Elko Burn 1 Results:

Two large mountain snowberry shrubs (heights 68, 100 cm; crown areas .5, 2.5 m^2, respectively) and one small shrub (height 33 cm; crown area .13 m^2) of snowberry were sampled. Their crowns were fused with those of surrounding big sagebrush plants, and grasses were growing up through their bases. Litter depth averaged 2 cm. The plants had shed their fruits and were in a dormant vegetative state.

The fire completely consumed each of the plants generating maximum temperatures of 1,600°F in their crowns and 1,400°F at the soil surface. Maximum sub-surface soil temperature at 1 and 2 cm was 250°F and 175°F, respectively.

All three plants were resprouting from their root crowns 1 year following the burn. By the 2nd year, the plants described above attained 63 percent, 30 percent, and 79 percent of their original height.

Elko Burn 2 Results:

Three mountain snowberry plants ranging from 70 to 90 cm tall, with crown areas between 1 and 2 cm were observed. Litter depths averaged 2 cm near the plants' bases. The shrubs were in a dormant state, having shed seed.

The October burn completely consumed all three individuals, leaving black ash 2 to 3 cm deep. Each plant resprouted the following year, as expected. Below normal precipitation (Figure 1) following the burn did not hinder resprouting.

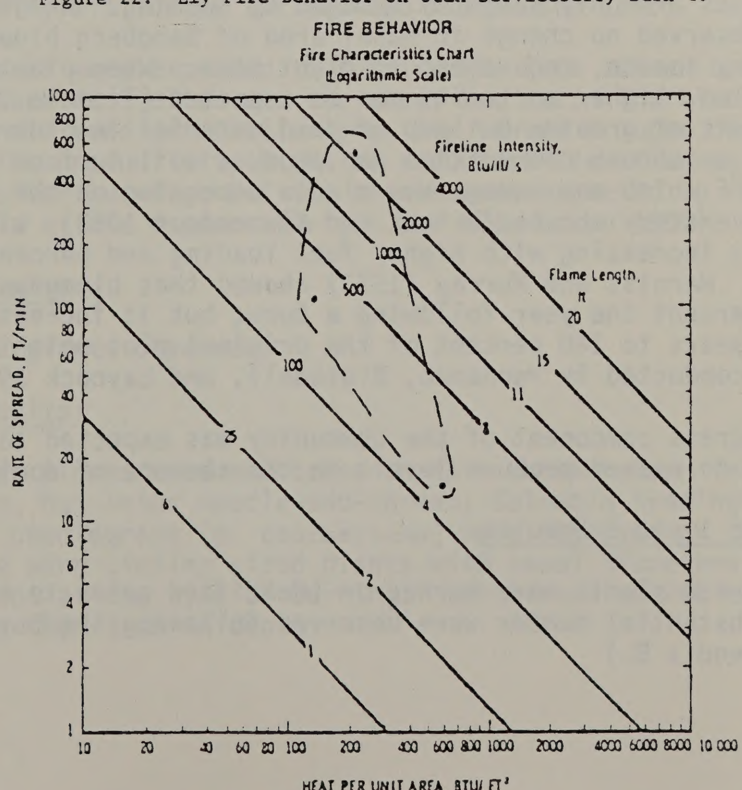
6. Utah serviceberry (*Amelanchier utahensis*) (Amut)

Utah serviceberry is slightly damaged by fire and resprouts (Wright 1972; Stanton 1974). Based on observations in southern Idaho and in Utah, no serviceberry mortality was expected to occur in these burns (Wright and others 1979).

Ely Burn 1 Results:

Four Utah serviceberry plants were tagged preceding the August burns on the Ely site. The plants averaged between 1 and 2 meters in height, and all were in the fruiting stage.

Figure 22. Ely Fire Behavior on Utah serviceberry Burn 1.



As seen in Figure 22, values for flame length and rate-of-spread were 5 to 15 ft and 100 to 500 ft/min, respectively. (Intensity and heat per unit area 190 to 2,020 BTU/ft/sec and 170 and 745 BTU/ft^2, respectively.) This fire behavior, though varied in intensity, resulted in fairly uniform defoliation of the plants. This was not expected in view of the 95 percent foliage moisture content. Stemwood greater than 1/8 inch remained intact.

Three of the four tagged plants were resprouting one growing season after the fire. The plant that died had 2.5 times more litter (5 cm) at its base prior to burning than did the surviving plants. During the fire the litter was consumed to white ash. The plant's death may be due to the extra heating it received in the zone of its dormant basal buds, as compared to the slight charring observed at the bases of the other plants.

Ely Burn 2 Results:

In the October burn, two additional Utah serviceberry plants were tagged. One sustained a much higher heat load than the plants in the July burn, with a heat per unit area value of 1,260 BTU/ft^2, but still resprouted. The other plant was unburned and not affected by the fire.

Elko Burns 1 and 2 Results:

No Utah serviceberry plants were found on the Elko sites.

7. Bluegrass (*Poa* spp.)

Expectations

Bluegrasses are only slightly damaged by burning. Wright and Klemmedson (1965) observed no change in basal area of Sandberg bluegrass (*Poa sandbergii*) during any season, regardless of plant size. When plants are older and pedestalled, higher mortality can be expected (Tisdale 1959). This occurs as a result of greater buildup of dead material in older and larger plants. Fires in sagebrush communities can produce soil surface temperatures greater than 400°F which may damage *Poa* plants depending on the percent cover and age of overstory shrubs (Wright and Klemmedson 1965), with fire intensity generally increasing with higher fuel loading and percentage of dead material present. Harniss and Murray (1973) showed that bluegrass production dropped off 25 percent the year following a burn; but it increased steadily over the next 39 years to 140 percent of the original plot weight (values taken from a study conducted by Pechanec, Blaisdell, and Laycock 1979, unpublished).

The bluegrass component of the community was expected to survive the burns and soon to exceed preburn levels in the absence of dominant sagebrush cover.

Ely Burns 1 and 2 Results:

No bluegrass plants were marked or identified prior to either burn 1 or 2; but a substantial number were observed following the burns. (See species list Appendix B.)

Elko Burns 1 and 2 Results:

Only one plant of Sandberg bluegrass was marked on the first Elko fire. It was dormant, having already shed seed by the time it was burned.

Although the plant had its above-ground parts totally consumed along with the entire clump of shrubs within which it was growing, it resprouted the next season. Peak temperatures had reached over 1,000°F in that location, well above the 400°F lethal limit cited by Wright and Klemmedson (1965).

8. Needlegrasses (*Stipa* spp.)

Expectations:

The effect of fire on needlegrass species depends largely on the growth form and season of burn (Blaisdell 1953; Wright 1971), especially if burned during the months of June or July (Wright 1971). The very dense plant material of these grasses burns slowly and long, charring down to the growing points (Wright 1971). This longer burnout period allows subsurface charring to take place. The more dead material that is present within the bunch, the more susceptible the plant is to damage (Wright 1971). Wright and Klemmedson (1965) found needle-and-thread (*Stipa comata*) showing 100 percent mortality in small plants and 90 percent mortality in large plants during June burns; 20 percent overall mortality for July burns; and no mortality for August burns.

Late summer or early fall burns are less damaging because plant material becomes more tolerant of heat as tissues dry (Wright 1971). Also, when root carbohydrate reserves are lowered during the plant fruiting stage, greater mortality will occur (Wright and Klemmedson 1965).

The needlegrasses were expected to survive the late summer burns because the plant tissues were dried and the seeds had set. The blackened soil should accelerate seed germination provided severe drought conditions did not follow. The productivity might be reduced in relation to unburned areas for one year after burning, but the plants were expected to recover or exceed unburned levels within 4 years (Wright and Klemmedson 1965).

Ely Burn 1 Results:

No needlegrass plants observed.

Ely Burn 2 Results:

Six needlegrass plants were monitored on this October burn (species were not identified, but later needle-and-thread; Columbia needlegrass; *S. columbiana*; and Thurber's needlegrass (*S. thurberiana*) were observed on the site (Kushler 1981)). These were similar sized plants with basal diameters of about 8 cm; all were dormant at the time of burning. Litter was sparce about the plants, averaging less than 1 cm in depth.

Flames varied in length from 10 to 20 feet, with rates-of-spread of 40 ft/min. Fireline intensity was calculated to be 3,770 BTU/ft/sec and heat per unit area 5,660 BTU/ft^2. Rapid fire spread only defoliated the plants, in some cases leaving 2 or 3 cm of charred stubble. Where ash was present, it was black in color.

Five plants were observed resprouting eight months after the fire. One plant was not burned and growing as before the fire. Some reasons for the recovery of the needlegrass are: the lack of accumulated dead material within the plants' bunches (these were fairly young, small individuals), the remoteness of heavy woody sage fuels and the lack of litter at the base of the plants, and perhaps most important, the plentiful rainfall that followed the burn. It should be noted that some of the plants had dead centers.

Elko Burn 1 Results:

One individual of Columbia needlegrass was observed. Its basal diameter was 5 cm, and the plant was dormant.

The fire consumed the plant totally, leaving black ash in its place. One year following the burn, the needlegrass was resprouting. Being located outside the exclosure, the plant showed signs of grazing. Removal of competition from sagebrush must have allowed this plant to survive despite below normal moisture available after the burn.

Elko Burn 2 Results:

Four Columbia needlegrass plants were marked on the October burn. All were dormant and averaged 5 cm of basal diameter. One plant was growing in a clump with snowberry and rabbitbrush shrubs.

Two of the four plants resprouted during the first season following the burn. Of the two that died, one had litter accumulated over 4 cm deep at its base, while the other was surrounded by highly flammable shrubs. In both cases, the death of the plants could be attributed to these external sources of heating or grazing impact, as this site was not fenced.

9. Bluebunch wheatgrass (*Agropyron spicatum*) (Agsp)

Expectations:

Bluebunch wheatgrass is slightly affected by burning. The season of burning strongly influences the degree of impact fire can have (Wright and others 1979). Plants burned in late summer and early fall show small decreases in basal area and undergo little mortality, whereas early summer burns kill 50 percent or more of the plants with large reductions in basal area (Conrad and Poulton 1966). These negative effects are usually evident in the first year following burning (Uresk and others 1976). Long-term studies (Blaisdell 1953) have observed bluebunch wheatgrass plots increasing production up to 12 years after burning, with an eventual decline after 30 years to levels

near or slightly below unburned plots (Harniss and Murray 1973). Barney and Freschknecht (1974) found cover of this grass to remain constant 40 years after burning in west central Utah, until reestablishment of a juniper overstory caused a decline.

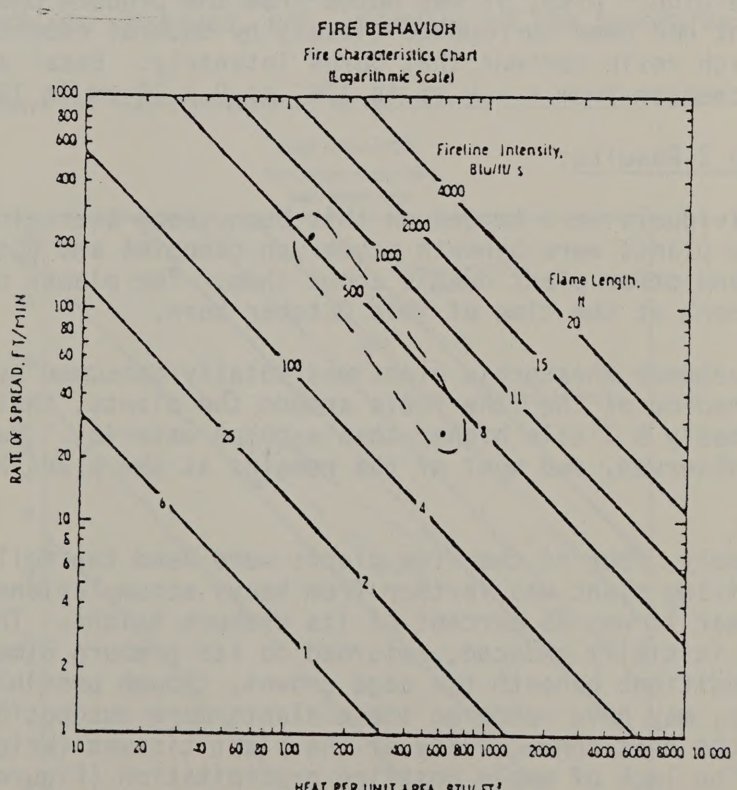
Plants of bluebunch wheatgrass were expected to survive the late August burn, with only a minor decrease in basal area. Full recovery is anticipated within three years (Blaisdell 1953; Moomaw 1957; Conrad and Poulton 1966; Uresk and others 1976, 1980).

Ely Burn 1 Results:

Three individuals of bluebunch wheatgrass were tagged prior to the August burn at Ely. Seed dispersal had been completed and the plants were in a dormant state. Figure 23 shows the fire behavior associated with this species.

Flames of 6 to 8 feet, moving at 25 to 200 feet per minute, burned in the vicinity of these plants. In terms of fireline intensity and heat per unit area, this fire behavior represents 280 to 500 BTU/ft/sec and 155 to 660 BTU/ft^2, respectively.

Figure 23. Ely Fire Behavior on Bluebunch wheatgrass Burn 1.



All the plants had only charred tufts remaining after the fire, but as expected, all were resprouting the following year. Two of the plants, however, showed a marked (25 to 75 percent) reduction in live basal area.

Ely Burn 2 Results:

No bluebunch wheatgrass plants were observed in the October 1980 burn.

Elko Burn 1 Results:

Two bluebunch wheatgrass plants were monitored on this burn. They had basal diameters of 7 cm and had already shed seed. Both individuals were located within clumps of several shrubs and other grasses, all of which were in contact with each other. Litter was approximately 2 cm deep and pedestalling was not indicated for either plant.

The late August burn completely consumed both plants down to white ash of about 2 cm depth. Maximum temperatures reached 2,000^{o}F within the crowns of the plants in the clump, dropping to 1,300^{o}F at the base of one bluebunch wheatgrass plant. Peak soil temperatures beneath this plant were 200^{o}F at 1 cm and 175^{o}F at 2 cm.

Eleven months after the fire, one plant was resprouting and the other dead. One possible explanation is that the surviving plant had its basal buds isolated from prolonged heating, even though the (1,300^{o}F) peak temperature was quite high. Also, it was noted from the preburn photographs that the dead plant had been surrounded closely by several rabbitbrush plants, which have a high resin content that burns intensely. Basal area of the surviving plant increased from ½ x ½ cm in 1981 to 9 x 14 cm in 1982.

Elko Burn 2 Results:

Five individuals were tagged on this burn, each averaging 8 cm in diameter. All these plants were beneath sagebrush canopies and had much dead grass foliage and other plant debris about them. The plants had shed seed and were dormant at the time of this October burn.

Every bluebunch wheatgrass plant was totally consumed by the fire. Because of the shading of the fine fuels around the plants, their moisture contents were probably a little higher than exposed material. Hence, little white ash was observed, and most of the remains at the plant bases were only charred.

Unexpectedly, four of the five plants were dead the following season. The one surviving plant was farther from heavy accumulations of litter. By the second year it was 65 percent of its preburn height. The basal area, although initially reduced, returned to its preburn dimension. The more moist conditions beneath the sage crowns, though possibly reducing the fire intensity, may have rendered these plants more susceptible to damage by raising the heat conductivity of the plant tissues (Wright and Klemmedson 1965). The lack of ample postfire precipitation (Figure 5) may also have reduced the wheatgrasses' chance for survival.

10. Bottlebrush squirreltail (*Sitanion hystrix*) (Sihy)

Expectations

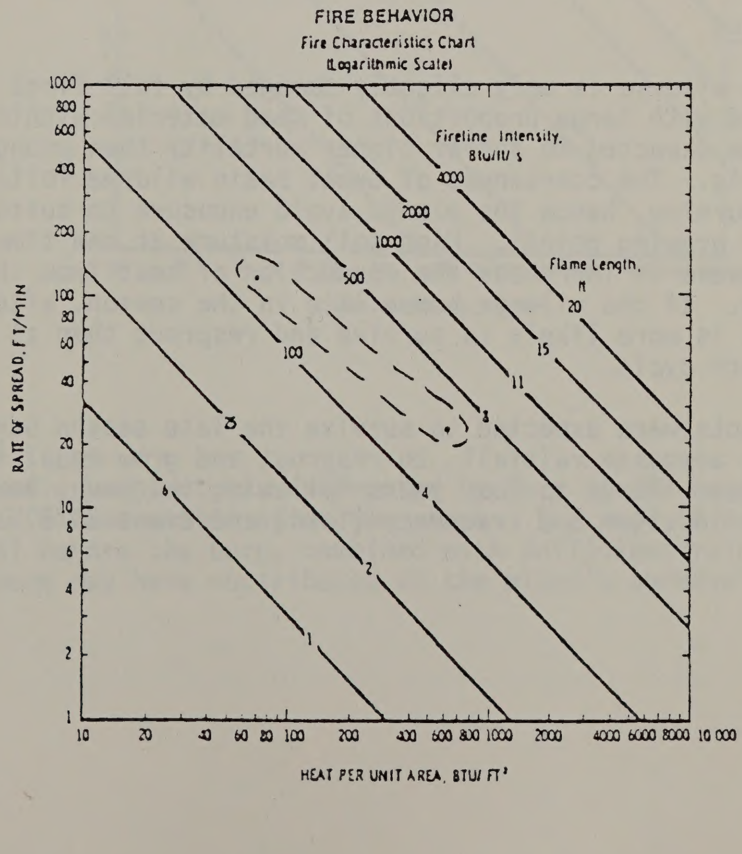
Bottlebrush squirreltail was expected to sustain some reduction of basal area in the July burn and undergo slight damage in the October burn; in both cases ultimately surviving the fires. The damage resistance of bottlebrush squirreltail can be attributed to its low density of dead plant material within the bunch (Wright and Klemmedson 1965; Wright 1971). As a result, the aerial plant parts burn quickly, with a minimum of heat penetration to the growing points. Other workers have found no mortality in squirreltail plants burned in mid-June and October (48 percent basal area reduction), but plants burned in mid-May in a drought year suffered 30 percent mortality (73 percent basal area reduction) (Wright and others 1979).

Ely Burn 1 Results:

Four plants were marked for observation in the late August burn. The plants were in the seed dispersal stage and averaged 12 cm basal diameter. The height ranged from 30 to 50 cm. Litter accumulations at the bases of the plants were from 0.5 to 2 cm in depth.

The fire burned the plants with an intensity of 200 BTU/ft/sec (5 ft flames), generating heats per unit area from 90 to 660 BTU/ft (see Figure 24). Surface temperature was recorded at over 1,000^{O}F at the bases of two plants, but no white ash was observed, only charring of the bunchgrass tufts.

Figure 24. Ely Fire Behavior on Bottlebrush squirreltail Burn 1.



The second year two plants died and were replaced by cheatgrass; one plant was severely damaged; and the fourth plant, which was pedestalled, recovered to 50 percent of its original height. Grazing pressure was evident on some of the plants.

Ely Burn 2 Results:

In the October burn, two bottlebrush squirreltail plants were marked for examination. Their basal diameters were 10 and 13 cm, with heights of 40 and 60 cm. These plants had slightly more dead material within their bunches than those of the July burn.

Fire behavior was much more intense on this burn, with fireline intensities of 3,770 BTU/ft/sec (20 ft flames) and heat per unit area of 5,660 BTU/ft^2. Nevertheless, the plants were only charred down to the basal tuft, and proceeded to sprout after one season, though they had less herbage than before the fire.

The survival of the squirreltail plants in both fires is probably the result of the fast fire rate-of-spread (20+ feet per minute) through the plants; as well as the above normal rainfall which followed that autumn (See Figure 2). Both plants developed dead centers, however.

Elko Burns 1 and 2 Results:

No individuals of this bunchgrass were found.

11. Great Basin wildrye (*Elymus cinereus*) (Elci)

Expectations:

Great Basin wildrye is only slightly damaged by fall fires (Vallentine 1971). Older plants with large proportions of dead material within the perennial crown can be expected to suffer higher mortality than younger plants having little debris. The coarseness of Great Basin wildrye foliage also resists prolonged burning, hence the plants avoid exposure to sustained heating of their basal growing points. High soil moisture at the time of burning is harmful because it increases the conduction of heat from the surface to the root system. If the wildrye burns late in the season, after having gone dormant, it is more likely to survive and resprout than at any other period in its growth cycle.

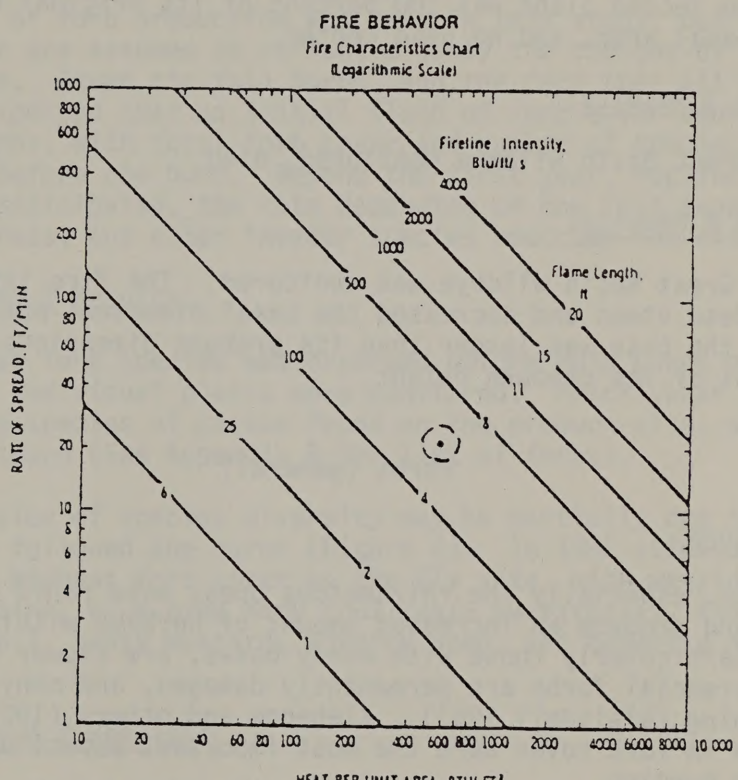
Wildrye plants were expected to survive the late season burns; and if followed by adequate rainfall, to resprout and grow equal to or greater than preburn rates. Three to four years following the burn, however, this grass may decline in vigor and frequency (Young and Evans 1978).

Ely Burn 1 Results:

One plant of wildrye was tagged for observation. The plant was 25 cm in basal diameter and dormant at burning time. Litter was accumulated to a depth of 6 cm surrounding its base.

Six foot flames (280 BTU/ft/sec) with a rate-of-spread of 25 ft/min (660 BTU/ft^2) defoliated the plant, leaving charred stubble. The maximum temperature recorded within the basal crown was 1,500°F. Figure 25 displays these data.

Figure 25. Ely Fire Behavior on Great Basin wildrye Burn 1.



Still, the wildrye plant had resprouted by July of the next season, although it developed a dead center after two years. Dry soil (6 percent taken at 15 cm depth) before the burn, combined with sufficient rainfall (Figure 2) after the burn may have contributed to the plant's survival

Ely Burn 2 Results:

Two Great Basin wildrye plants were monitored. Basal diameters were 65 and 49 cm, with litter averaging a depth of 3 cm. Both plants were in a dormant state when burned.

A fire many times more intense than that in Burn 1 only defoliated the plants. Flames were 20 feet long (3,770 BTU/ft/sec), rate-of-spread was 40 ft/min, and heat per unit area was 5,660 BTU/ft^2. Blackened stems and leaves measuring 12 cm long remained over the base area of the plants.

Both plants survived the burn, as resprouting was observed the following season. By the second year, one plant sprouting from five areas on the old crown, attained 50 percent of its original height, but had a reduced basal area. The second plant was 100 percent of its original height, had a slightly reduced basal area, and no dead center.

Elko Burn 1 Results:

The one Great Basin wildrye monitored, died.

Elko Burn 2 Results:

Only one Great Basin wildrye was monitored. The fire initially burned the coarse, dead stems and decreased the basal diameter; but by second year postburn the base was larger than its preburn dimensions. The plant was 73 percent of its preburn height.

12. Forbs (general)

Expectations:

Many forbs, especially the rhizomatous ones, make rapid recovery after burning and produce an increased amount of herbage within three years. Others, particularly those with woody bases, are slower to recover. None of the perennial forbs are permanently damaged, and many apparently benefit from burning (Blaisdell 1953). Klebenow and others (1977) found that increases in forb cover were the most important aspect of succession following burning.

Forbs that are dormant at the time of burning are not harmed; whereas, forbs actively growing or flowering are susceptible to damage (Britton 1978). Most forbs have set seed and are disintegrated by the fall, which is why burning is least harmful at that time. Pechanec and Stewart (1944) classified forbs according to their susceptibility to fire. In a later study, Pechanec and others (1954) observed that forb species that spread by rootstocks increase more rapidly after burns than those reproducing by seeds alone. In the latter group, such species as arrowleaf balsamroot (*Balsamorhiza sagittata*) and tailcup lupine (*Lupinus caudatus*) were expected to make an initial flush after the fire, drawing on previously stored seeds. Further increases, however, would have to await more seed production.

Blaisdell and others (1953) saw forbs one year after a fire increase in density and biomass 30 to 60 percent over unburned areas, and increase 30 to 100 percent after 3 years. (Their study was conducted on the Snake River Plains, Idaho, a site similar to the Elko site.) Twelve years after the burn, total forb yield on the burned plots was still higher than on the unburned plots. But 30 years later, Harniss and Murray (1973) showed that these trends were reversed as sagebrush gradually returned to dominate the site.

Blaisdell (1953) also noted an inverse relationship between forb production and fire intensity. Higher intensity burns had lower forb production. This was probably the result of the fire's destruction of stored seeds and damage to rootstocks of dormant plants.

No assessment of forb production was made in this study, but changes in relative cover are assumed to reflect closely the changes of forb density and production. Given the fall burns, and the fact that all the forbs were dry, it was expected that an initial flush of forb cover would immediately follow the burns, with total forb cover and number of species markedly greater than before the burn. Beyond the first year, decline of the forb component is anticipated, the rate depending on how fast sagebrush, rabbitbrush, cheatgrass, and other invader species reoccupy the site.

Ely Burns 1 and 2 Results:

Only a trace of forb species was observed before both burns on the Ely site; therefore, no individual plants were monitored. Pricklypear (*Opuntia polyacantha*) a species of cactus found on the preburn site, was not seen two years postburn (See Appendix B for list of forbs).

Such an explosion of species diversity may be partially due to the plentiful rainfall that followed the burns (Figure 2). In 1982 stickseed (*Hackelia* spp.) had the highest forb cover on the Ely site, with wayside gromwell, milkvetch, lupine, blue-eyed Mary (*Collinsia parvifolia*), fiddleneck (*Amsinckia* spp.), tansy mustard, poverty weed, and tapertip hawksbeard also tallied.

Elko Burns 1 and 2 Results:

In burn 1, two individuals of mint (*Agastache urticifolia*), and one each of lupine and arrowleaf balsamroot were tagged; in burn 2, only two mints were marked.

Observations of these plants immediately after burn 1 indicated that both mint plants had all of their above-ground parts completely consumed. This was also true of the balsamroot and lupine plants. Maximum surface temperatures on these individuals were recorded at 1,200°F to 1,500°F. Soil temperatures reached peaks of 250°F and 175°F at 1 and 2 cm below the surface, respectively. Little can be said regarding the linkage of surface peak temperature with ash conditions, since half the cases of 1,200°F temperatures had black ash remaining, and on the other half white and grey ashes were present.

Both mint plants were totally consumed by the second burn, leaving a residue of white ash.

Resampling both burn sites in July of 1981 showed that the balsamroot plant was killed by the August burn, probably as a result of the burnout of adjacent woody sage fuels. The lupine and mint plants resprouted, with lupine being the most abundant forb on the site as a whole. Only one of the two mint plants survived the October burn, perhaps because it was more isolated from surrounding fuels than the plant that died. However, this site was not fenced, and the sprouting plant may have been eaten by cattle or deer. Complete precipitation records for this site are lacking, but general estimates indicate that rainfall levels were slightly below normal following the burn, accounting partly for the relatively low forb species diversity on the site. In 1982, lupine had the highest forb cover (67 percent) on Elko Burn 1. On the Elko Burn 2 site, mint had the highest forb cover (63 percent).

The forb component on Elko Burn 1 increased from 1.2 percent cover preburn, to 1.6 percent one year postburn, to 16.2 percent two years postburn. On Elko Burn 2, the forb component again increased from 0 percent preburn, to 14 percent one year postburn, to 34 percent two years postburn. Cover values for the Ely site were erratic, possibly due to heavy grazing by rabbits.

Forb recovery on the Carson site was slow during the first year postburn. During a year of above normal precipitation, forbs made up only 0.3 percent of the cover.

VI. RECOMMENDATIONS

During the past three years we have observed fire behavior and plant response on eight study burns. Although we have learned a great deal from this experience, there is much more to learn regarding fuels, fire behavior, and fire effects in the Great Basin.

As resource managers use fire on an increasing basis there comes a growing demand for accurate prediction of fire behavior and its influence on soils, air, water, plants, animals, and man. The following recommendations for future study will help to fulfill these needs.

1. Continue to record the vegetational changes that are occurring on the transects of the three burn sites.

2. Continue to record preburn plant data and fire behavior data on all prescribed burns conducted in the state. Assist the districts in collecting fire effects data on the following species: bitterbrush, green rabbitbrush, rubber rabbitbrush, western wheatgrass, Idaho fescue, cheatgrass, halogeton, leafy spurge, and other poisonous plants.

3. Develop procedures for mapping fire behavior on large prescribed burns that will permit correlation with plant response.

4. Create a statewide catalogue system that will store site, fire behavior, and plant response data in a file to be used as a reference for future prescribed burn planning. Coordination between the Branch of Renewable Resources and the Branch of Protection will be necessary.

5. Develop a Nevada fuels photo series. This will include a representative photo of each fuel complex; fuel loading by size class of fuel; average height of fuels; percent cover of trees, shrubs, and grasses; live to dead ratio; stand age; average litter depth; fire behavior and resistance to control predictions (flame length and rate-of-spread at windspeed of 0-30 mph); and a brief site description with dominant species response to fire.

6. Develop a list of Nevada plants and how they respond to fire. It must consolidate all published information into one document and should consider growth form, reproductive system, and varying fire intensities. This recommendation has a direct tie with recommendation number 4.

7. Develop a form for evaluating potential prescribed burn sites. It should address goals and objectives, management issues and public concerns, site description, operations, logistics, cost estimates, safety, and recommendations.

8. Prepare a slide/tape or video presentation that illustrates the collection of data and plant responses described in this report. The slide/tape or video presentation can then be distributed to offices within the state and to others who are interested in the project. This should encourage use of the statewide catalogue described in item 4 and aid in planning prescribed burns.

9. Although the Carson City District study site was not designated for fire effects observation, several species warrant follow-up. The following tagged plants should be observed: antelope bitterbrush, gray horsebrush (*Tetradymia canescens*), desert peach (*Prunus andersonii*), green rabbitbrush, Great Basin wildrye, and Mormon tea (*Ephedra vividis*).

10. Additional fire behavior information is needed from monitored burns to determine acceptable ranges of fuels, weather, and topography needed to meet specific management objectives in a safe, cost effective manner. The data obtained from this process will be placed in the catalogue described in item 4.

VII. LITERATURE CITED

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APPENDIX A

Soil Chemical Analysis on Ely Burn 1

8/8/80 Preburn

Sample Number	Salinity Hazard (E Ce)	Sodium Hazard (SAR)	pH	Phosphorous (ppm)	Potassium (ppm)	NO3-N (ppm)
1	0.45	0.80	6.60	25	119	10
2	1.0	0.70	6.60	25	172	10
3	0.9	0.20	6.90	25	235	10
4	1.0	0.13	6.90	25	254	10
$\bar{X}$	0.85	0.46	6.75		195	

8/29/80 Postburn

Sample Number	Salinity Hazard (E Ce)	Sodium Hazard (SAR)	pH	Phosphorous (ppm)	Potassium (ppm)	NO3-N (ppm)
1	1.9	0.50	7.50	25	312	10
2	1.7	0.70	7.30	25	332	10
3	1.7	0.20	7.50	25	361	10
4	1.9	0.20	7.50	25	273	10
$\bar{X}$	1.8	0.40	7.45		320	

The trend between the preburn and postburn samples is an increase in salinity and potassium, along with a rise in pH. Sodium, phosphorous, and nitrate-nitrogen exhibited little differences. These results showed a 53 percent increase in soluble salts. This however, is not significant since the E Ce value remained below 2, presenting no problems for plant growth. The potassium increased 39 percent, from an average of 195 ppm to 320 ppm. Both preburn and postburn K levels are adequate for plant growth. The pH increased 0.7 unit, from an average of 6.75 to 7.45; this is significant (Kiracofe 1981; personal communication).

APPENDIX B

Ely Species List

The following is a list of species found in the Horse Haven area. Those marked by an "X" are plants found specifically within the actual burn sites (Kushler 1981).

	Scientific Name	Common Name	Within Burn
SHRUBS	*Purshia tridentata*	antelope bitterbrush	X
	Artemisia tridentata	big sagebrush	X
	Chrysothamnus viscidiflorus	green rabbitbrush	X
	Symphoricarpos utahensis	Utah snowberry	X
	Amelanchier utahensis	Utah serviceberry	X
	Tetrademia canescens	gray horsebrush	X
FORBS	*Opuntia polyacantha*	prickly pear cactus	X
	Penstemon watsonii	Watson penstemon	X
	Erigeron sp.	daisy	X
	Lupinus sp.	lupine	X
	Sphaeralcea parvifolia	globemallow	X
	Iva axillaris	poverty weed	X
	Lappula redowskii	stickseed	X
	Lygodesmia spinosa	spiny skeleton weed	
	Descurainia pinnata	tansy mustard	
	Argemone platyceras	prickly poppy	
	Nicotiana attenuata	Indian tobacco	
	Vicia sp.	vetch	
	Gilia congesta	baldhead gilia	
	Amaranthus graecizans	pigweed	
	Crepis acuminata	tapertip hawksbeard	
	Lithospermum ruderale	wayside gromwell	
	Hackelia patens	stickseed	
	Cryptantha sp.	-	
GRASSES	*Bromus tectorum*	cheatgrass	X
	Sitanion hystrix	bottlebrush squirreltail	X
	Stipa comata	needle-and-thread grass	X
	Stipa columbiana	Columbia needlegrass	X
	Stipa thurberiana	Thurber's needlegrass	X
	Agropyron spicatum	bluebunch wheatgrass	X
	Poa sandbergii	Sandberg bluegrass	X
	Elymus cinereus	Great Basin wildrye	X

APPENDIX C

Burn Comparison - Fire Characteristics Chart